Transactions of the

AMERICAN FOUNDRYMEN'S ASSOCIATION

PROCEEDINGS OF THE
TWENTY-EIGHTH ANNUAL MEETING
MILWAUKEE, WISCONSIN
OCTOBER 13 TO 16, 1924

Volume XXXII
Part I

REPORTS AND PAPERS
Presented at the Milwaukee Meeting
except those on Foundry Sand Investigation

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Summary of the Proceedings of the Twenty-eighth Annual Meeting

Milwaukee, Wis., Oct. 11 to 16, 1924

The twenty-eighth annual meeting of the American Foundrymen's Association and annual exhibit of foundry equipment and supplies was held at the Milwaukee Auditorium, Milwaukee, Wisconsin, October 11th to 16th, inclusive.

This meeting, excelling all previous meetings in attendance of registered members and guests, proved one of the most successful ever held by the Association. The registration, exceeding the previous high registration, indicates the greater recognition of the value of these meetings which the men of the industry are placing on attendance at these meetings.

As has been the custom in the past, the Institute of Metals Division of the A. I. M. E. held its fall meeting to coincide with the annual meeting of the A. F. A., two joint sessions of these organizations being held at which topics of non-ferrous foundry interest were discussed.

The technical program, consisting of ten A. F. A. sessions and two joint sessions with the Institute of Metals Division of the A. I. M. E., brought out the best group of research papers ever before presented at our meetings. Every phase of the industry was well covered. Sand research and apprentice training proved of greatest interest as attested by the record-breaking attendance at these sessions. Apprentice training was given additional prominence by the exhibit of apprentice training organization material placed on display by the Falk Corporation and the apprentice competition organized under the auspices of the A. F. A. and the Milwaukee Metal Trades Association. This competition, which took place in the foundry of the Milwaukee Vocational School, was divided into separate competition of first, second, and third year classes of the gray iron and steel foundry apprentices from the Milwaukee foundries.

The prizes donated by the A. F. A. were awarded as recommended by the judging committees, whose reports follow:

To The American Foundrymen's Association:

Your committee appointed to judge the competition among gray iron foundry apprentices of the Milwaukee district is pleased to report as follows:

Charles Liebschl has been awarded first prize in the third year class; Benjamin Pinkalski has been awarded the prize in the second year class. Your committee could find nothing to differentiate between the work of the boys in the first year class and therefore recommend that the prize be equally divided among the three.

Signed: J. J. WILSON
BEN FULLER
PAT DWYER
A. F. A. Committee of Judges for Gray Iron Apprentice Competition

To The American Foundrymen's Association:

Your committee appointed to judge the competition among steel apprentices of the Milwaukee district is pleased to report as follows:

Andrew Bottoni is awarded the prize in the first year class; Ralph G. Meehan the prize in the second year class; Paul Buth the prize in the third year class, and Martin Wald and Reinhard Barkow of the fourth year class are to share equally in the prize of this group. William Cunningham is awarded the prize in the special apprentice class.

Signed: J. C. GREEN
W. J. CORBETT
R. M. SCOTT
J. H. PLOEHN
A. F. A. Committee of Judges for Steel Apprentice Competition

Forty-seven technical papers and fifteen technical committee reports were presented at the various sessions, the papers being divided between the sessions as follows:

10 Non-ferrous topics
6 Steel foundry topics

5 Apprenticeship discussions
10 Sand research investigations
4 Electric furnace cast iron topics
4 Malleable cast iron topics
5 Cast iron metallurgy topics
2 Cost-finding discussions
1 Review of international foundry progress

The fifteen technical committee reports detailed progress in investigation of the problems of the industry. Of greatest significance, these reports indicate the part that cooperative investigation is attaining in solving industrial problems. Such a trend shows clearly that more and more are manufacturers coming to realize that trade secrets are of the past generations. For individual firms to progress, they must pool their resources for investigation, giving of their best and receiving, in return, the best of the industry as a whole.

This interchange of information in the foundry field has been extended to international proportions made possible by the exchange arrangement with the European foundry associations which calls for an annual exchange of papers. This year three foreign papers appeared on the A. F. A. program, these papers being: *Modern bell founding* by Wesley Lambert and G. Hall of London, the Institute of British Foundrymen's contribution; *Alpax, a new development of aluminum alloys* by Leon Guillet, Paris, and *A new mold hardness tester* by E. Ronceray, Paris, these last two papers being contributions of the Association Technique de Fonderie de France. A detailed summary of the technical sessions follows:

Session No. 1—Brass Founding

Joint Session A. F. A. and Institute of Metal Division A. I. M. E. Monday, Oct. 13, 1:30 p. m.

President G. H. Clamer in the chair, with G. K. Elliott, chairman of the Institute of Metal Division, as associate chairman.

Papers and report read and discussed were as follows:

MAKING COPPER CASTINGS FROM CUPOLA MELTED METAL, by T. F. Jennings, Garfield, Utah—presented by the author.

MODERN BELL FOUNDING, by Wesley Lambert and G. Hall, London, England. This, the annual Institute of British Foundrymen's exchange paper, in the absence of the authors was presented by Verne E. Minich, a member of the A. F. A. Board of Directors.

FOUNDING BRASS IN MEXICO, by H. H. Miller, Torreon, Coa, Mexico—presented by title.

ART BRONZE WORK, by J. F. Arnold, Mt. Vernon, N. Y.—presented by title.

REPORT OF COMMITTEE ON NON-FERROUS METALS—presented by the committee chairman, J. L. Jones.

THE COPPER REFINING INDUSTRY—Motion picture films explained by G. F. Stanton, The Baltimore Copper and Rolling Company.

The report of the Committee on Non-Ferrous Metals was by action of the meeting recommended to the Board of Directors for approval as a progress report.

Session No. 2—Steel Founding

Monday, Oct. 13, 1:30 p. m.

A. H. Jameson in the chair, S. W. Utley, associate chairman.

The papers and reports read and discussed were:

BROADENING THE FIELD FOR STEEL CASTINGS THROUGH THE USE OF ALLOYS AND HEAT TREATMENT, by F. Grotts, The Holt Mfg. Co., Peoria, Ill.—presented by M. L. Frey.

REPORT OF COMMITTEE ON SPECIFICATIONS FOR STEEL CASTINGS—presented by A. H. Jameson, chairman of the committee.

REPORT OF COMMITTEE ON REFRACTORIES—presented by C. N. Ring, chairman of the committee.

THE MICROSCOPE AS A CONTROLLING INSTRUMENT IN ANNEALING STEEL CASTINGS, by J. Fletcher Harper and H. J. Stein, Allis-Chalmers Mfg. Corp., Milwaukee, Wis.—presented by H. J. Stein.

THE HEAT TREATMENT OF STEEL VALVE CASTINGS IN THE ELECTRIC FURNACE, by V. T. Malcolm and A. Sproat, The Chapman Valve Co., Indian Orchard, Mass.—presented by V. T. Malcolm.

The two committee reports were approved by the meeting with the recommendation that they be accepted by the Board of Directors as progress reports. Following the presentation of the report of the Committee on Refractories a motion was made and approved as follows:

That it be the sense of the members of the Association present that a recommendation be made to the Board of Directors that an attempt be made leading to a possible coordinated effort on the part of all organizations and societies interested in refractories for the purpose of carrying out the recommendations as presented by the committee, for it seems highly desirable that no duplication of effort be made in this matter and that by a cooperative effort considerable benefit might accrue to the foundry industry.

Session No. 3—Aluminum Alloys

Joint Sessions A. F. A. and Institute of Metals Division A. I. M. E.

Tuesday, Oct. 14, 9:30 a. m.

Secretary W. M. Corse of the Institute of Metals Division in the chair, Vice-President L. W. Olson, associate chairman.

The subject of aluminum alloys was covered by the following papers:

PRODUCTION OF ALUMINUM ALLOY PISTONS IN PERMANENT MOLDS, by R. J. Anderson, Boston, Mass., and M. E. Boyd, Clinton, Mich.—presented by J. B. Chaffee.

FOUNDRY TREATMENT AND PHYSICAL PROPERTIES OF SILICON-ALUMINUM ALLOYS, by D. Basch, General Electric Co., and M. F. Sayre, Union College, Schenectady, N. Y.—presented by D. Basch.

ALUMINUM ALLOY CASTINGS FROM SHEET SCRAP, by H. C. Knerr, Philadelphia, Pa.—presented by title.

SALVAGE OF ALUMINUM ALLOY CASTINGS BY WELDING AND SOLDERING, by R. J. Anderson, Boston, Mass., and M. E. Boyd, Clinton, Mich.—presented by Jesse L. Jones.

ALPAX, A NEW DEVELOPMENT OF ALUMINUM ALLOYS, by Dr. Leon Guillet, Paris, France, translated by R. J. Anderson—presented by D. Basch.

Session No. 4—Steel Founding

Tuesday, Oct. 14, 9:30 a. m.

John Howe Hall in the chair, W. J. Nugent, associate chairman.

The papers and reports presented and discussed were:

REPORT OF A. F. A. REPRESENTATIVE ON JOINT INVESTIGATION OF PHOSPHORUS AND SULPHUR IN STEEL—presented by Major R. A. Bull, A. F. A., representative on committee.

ORGANIZATION AND PRACTICE IN A STEEL FOUNDRY FINISHING ROOM, by C. W. Heywood, Burnside Steel Co., Chicago—presented by A. W. Gregg.

NOTES ON THE OVERALL PERFORMANCE OF ACID ELECTRIC FURNACES, by T. S. Quinn, Lebanon Steel Foundry, Lebanon, Pa.—presented by the author.

X-RAYS IN THE FOUNDRY, by Dr. Ancel St. John, New York, N. Y.—presented by the author.

REPORT OF COMMITTEE ON HEAT TREATMENT OF FERROUS CASTINGS—presented by Major R. A. Bull, chairman of the committee.

The two committee reports were accepted as read and the meeting recommended that they be presented to the Board of Directors for approval.

Session No. 5—Apprentice Training

Tuesday, Oct. 14, 9:30 a. m.

H. S. Falk in the chair, Wm. Watson, associate chairman.

Two groups of papers were read and discussed at this session. Of the first group of three, two were written from the employer's viewpoint and one from the point of view of a director of vocational education. Of the second group of two, both were written from the viewpoint of graduate apprentices. These papers were presented as follows:

1st Division.

THE EMPLOYER'S EXPECTATION OF APPRENTICESHIP, by R. J. Doty, The Sivyer Steel Casting Co., Milwaukee, Wis.

THE MILWAUKEE DISTRICT PROGRAM, by H. S. Falk, The Falk Corporation, Milwaukee.

THE MILWAUKEE VOCATIONAL SCHOOL, by R. L. Cooley, Director, Milwaukee Vocational School, Milwaukee.

2nd Division.

APPRENTICESHIP FROM THE APPRENTICE'S VIEWPOINT, by J. Edwards, Milwaukee.

WHY I TALK APRENTICESHIP, by C. Freund, Milwaukee.

Session No. 6—Foundry Sands

Tuesday, Oct. 14, 1:30 p. m.

W. M. Saunders in the chair, Past President R. A. Bull, associate chairman.

The following committee reports and papers on foundry sand research read and discussed were largely prepared as results of the investigations being carried out under the auspices of the Joint Committee on Molding Sand Research of the A. F. A. and National Research Council.

REPORT OF CHAIRMAN OF JOINT COMMITTEE ON MOLDING SAND RESEARCH—presented by W. M. Saunders, general chairman of the joint committee.

REPORT OF SUB-COMMITTEE ON TESTS—presented by Dr. H. Ries, chairman of the sub-committee on tests.

REPORT OF SUB-COMMITTEE ON GEOLOGICAL SURVEYS OF FOUNDRY SANDS—presented by Dr. H. Ries, chairman of the sub-committee on geological survey.

INVESTIGATION OF THE MOLDING SAND RESOURCES OF ILLINOIS—presented by M. M. Leighton, Chief, Illinois Geological Survey.

DEVELOPMENT AND COMPARISON OF PERMEABILITY TESTING APPARATUS, by T. C. Adams, Cornell University, Ithaca, N. Y.—presented by the author.

COMMERCIAL APPLICATION OF MOLDING SAND TESTING, by H. W. Dietert, U. S. Radiator Corp., Detroit, Mich.—presented by the author.

RELATION OF WATER TO BOND AND PERMEABILITY, by C. M. Nevin, Cornell University, Ithaca, N. Y.—presented by Dr. H. Ries.

A STUDY OF THE EFFECT OF HEAT ON THE CLAY CONTENT OF MOLDING SANDS AS SHOWN BY THE DYE ADSORPTION TEST,

by R. F. Harrington, W. L. MacComb, and M. A. Hosmer, The Hunt-Spiller Mfg. Corp, Boston, Mass.—presented by R. F. Harrington.

Following the reading of the paper by Dr. Leighton of the Illinois Geological Survey, Dr. H. Ries introduced the following resolution:

Inasmuch as The Illinois Geological Survey has completed a study of the molding sand resources of Illinois, including standardized laboratory tests, in cooperation with the College of Engineering Experiment Station, and,

Inasmuch as this study was undertaken at the suggestion of the American Foundrymen's Association for the benefit of the foundry industry,

We respectfully urge that the results be published and made available at as early date as possible.

This resolution, seconded by Past President R. A. Bull, was adopted by the meeting.

The committee reports presented were accepted as progress reports with the recommendation that they be approved by the Board of Directors.

Session No. 7—Foundry Sand Research

Wednesday, Oct. 15, 9:30 a. m.

W. M. Saunders in the chair, R. J. Doty, associate chairman.

This session was a continuation of the presentation of the group of papers and reports which was begun in session No. 6.

REPORT OF SUB-COMMITTEE ON CONSERVATION AND RECLAMATION—presented by F. L. Wolf, chairman of the sub-committee.

THE PHYSICAL PROPERTIES OF FOUNDRY SAND, by C. A. Hansen, General Electric Co., Schenectady, N. Y.—presented in abstract form by H. W. Dietert.

NOTES ON THE GRADING OF SANDS, by C. M. Nevin, Cornell University, Ithaca, N. Y.—presented by Dr. H. Ries.

A STUDY OF VARIOUS MOLDING SAND MIXTURES, TOGETHER

WITH THE PHYSICAL PROPERTIES OF THE MOLDS AND CASTINGS PRODUCED, by R. F. Harrington, A. S. Wright, and M. A. Hosmer, The Hunt-Spiller Mfg. Corp., Boston, Mass.—presented by R. F. Harrington.

A NEW MOLD HARNESS TESTER, by E. Ronceray, Paris, France. Annual exchange paper of the Association Technique de Fonderie de France—presented by Robert Ronceray.

MOLDING SAND RECLAMATION AND CONTROL EXPERIMENTS, by F. L. Wolf and A. A. Grubb, The Ohio Brass Co., Mansfield, Ohio—presented by A. A. Grubb.

Session No. 8—Electric Furnace and Cast Iron

Wednesday, Oct. 15, 9:30 a. m.

Past President L. L. Anthes in the chair, G. K. Elliott, associate chairman.

ELECTRIC FURNACE GREY IRON, by E. L. Wilson, Hartford, Conn.

THE ELECTRIC FURNACE IN THE PIPE FOUNDRY, by J. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.—presented by the author.

SYNTHETIC FOUNDRY IRON, by C. E. Williams, C. E. Sim, and K. W. B. Worsöe, U. S. Bureau of Mines, Seattle, Wash.—presented by C. E. Williams.

REPORT OF COMMITTEE ON CORROSION OF FERROUS METALS—presented by H. Y. Carson, chairman of the committee.

FIRST PROGRESS REPORT OF SOIL CORROSION INVESTIGATION CONDUCTED BY THE U. S. BUREAU OF STANDARDS, by K. H. Logan, U. S. Bureau of Standards, Washington, D. C.—presented by H. Y. Carson.

Session No. 9—Business Meeting

Wednesday, Oct. 15, 2:00 p. m.

President G. H. Clamer in the chair, Vice-President L. W. Olson, associate chairman.

Secretary C. E. Hoyt read the report of the Nominating Committee, nominating the following officers and directors:

For president to serve for one year: Louis W. Olson.

For vice-president to serve for one year: A. B. Root.

For director to serve for one year to fill the place left vacant by the elevation of A. B. Root to the position of vice-president: V. E. Minich.

For directors to serve for three years: G. H. Clamer, J. E. Galvin, A. E. Hageboeck, R. A. Nourse, W. J. Nugent.

These nominees were declared elected, as the by-laws of the Association provide that in the event no other nominees were presented by petition after the publication of the report of the Nominating Committee, the candidates nominated by the Nominating Committee shall be declared elected. The newly elected officers were then introduced by Chairman Clamer.

President-elect Olson, assuming the chair, then called upon Secretary Hoyt to read the report of the meeting of the Board of Directors of Oct. 12, 1924, recommending the election to honorary membership of President G. H. Clamer. A motion was made and unanimously carried approving the recommendation of the Board that honorary membership be conferred upon the retiring president, G. H. Clamer.

President Clamer next read the annual address of the president. This address will be found on page 1 of this volume.

The report of the committee on the Obermayer Prize of the A. F. A. was read. This report recommended as the winner of the prize, Herman Honold, foundry superintendent, of the East Cambridge, Mass., plant of the Worthington Pump and Machinery Corp.

President Clamer then, in the name of the association, presented to Mr. Honold the prize, an engraved clock. Mr. Honold made a short speech of acceptance.

A. O. Backert, chairman of the Committee on Resolutions, read the resolutions which had been drawn up and which were as follows:

For the third time since its organization, the American Foundrymen's Association has been the guest of the thriving and enterprising city of Milwaukee. For the third time the members

and guests of this body have enjoyed the bountiful hospitality of the people of this great industrial community. Milwaukee's greeting to these visitors always has been marked by the most sincere cordiality and, if that were possible, it seems to grow in warmth with each succeeding visit.

Therefore be it resolved, That the American Foundrymen's Association extends to the good people of Milwaukee in general, and to the Milwaukee Metal Trades and Founders Association, and the Milwaukee Association of Commerce in particular, its deep appreciation of the generous hospitality accorded to its members and guests. To the men and women constituting the various local committees, who were untiring in their efforts to make this visit notably enjoyable, special thanks should be accorded. To the Hotels, to the Management of the Milwaukee Auditorium, and to all other agencies and individuals, who contributed to the entertainment and comfort of the members and guests of the American Foundrymen's Association in attendance at this convention, deep appreciation is extended.

Apprentice Training

One of the greatest problems confronting American Manufacturers of Castings, is the future supply of skilled mechanics which is inadequate to fill depleting forces, to say nothing of meeting the needs of an expanding industry. The apprenticeship training of young men in the art of Founding, has met with such marked success in the Milwaukee Vocational School, that it is evident that another obstacle in foundry progress has been overcome.

Therefore, be it resolved, That the American Foundrymen's Association views with favor the methods pursued by this School in the training of Foundry Apprentices and commends to its members the establishment of similar schools in their respective communities.

Technical Program

Never before in its history has the American Foundrymen's Association offered its members such an extensive and varied program of technical papers and committee reports. In this connection the work of the Sand Research Committee should be singled out as one of the great accomplishments of the past two

years. The magnificent program presented this week was made possible only by the unselfish contributions of many noted authorities on all phases of foundry work. They have given generously of their knowledge and freely of their time, that others might benefit from the results of their studies, experiments and research. To these authors and committee workers the casting industry of the world owes a debt of gratitude, and the American Foundrymen's Association votes its acknowledgment of this debt, and extends to them its great appreciation and thanks for their contributions, which record further advances in the art of Founding.

Exhibits

The exhibition of foundry supplies and equipment conducted concurrently with this convention, reflected in concrete form the great progress made in casting manufacture in a period of eighteen months. This year the number of individual exhibits is second only to the high mark set at Columbus. To the Manufacturers who contributed to the success of this great undertaking the American Foundrymen's Association feels deeply indebted and hereby expresses its appreciation and thanks.

Appreciation

Behind the activities of this great Association is an executive organization whose only compensation is the constantly increasing success of this leading body of casting manufacturers of the world. The men constituting this executive staff have been untiring in their zeal in your behalf; they have given generously of their time to the conduct of the affairs of your Association. They have guarded your finances with the same care and with that same degree of conservatism that they surround their own private affairs. Therefore, let us express to our retiring president, G. H. Clamer, to our former vice-president and president-elect, L. W. Olson, and to our Board of Directors, our great appreciation of their efforts, by a rising vote of thanks.

Resolutions respectfully submitted by

Resolutions Committee

A. O. BACKERT, *Chairman,*
W. R. BEAN,
V. E. MINICH.

The report of the Resolutions Committee was unanimously adopted. A motion was made and carried that a copy of the resolutions should be sent to the director of the Milwaukee Vocational School.

Following the reading of the resolutions, the secretary read invitations received from various cities for the Association meeting in 1925. In accordance with past practice and regulations, these invitations were referred to the Board of Directors for consideration.

The recommendation made by the Board of Directors that the A. F. A. hold an international convention in this country in 1926 was next read. This recommendation was put in the form of a motion and approved by the meeting.

The meeting was concluded by H. Cole Estep, chairman of the Committee on International Relations, reading his paper entitled, "A World Outlook for American Foundrymen."

Session No. 10—Foundry Costs

Wednesday, Oct. 15, 3:00 p. m.

C. B. Connelley in the chair, L. S. Peregoy, associate chairman.

The papers and reports read were as follows:

COST FINDING IN A FOUNDRY, by W. J. Corbett, Electric Steel Founders' Research Group, Chicago—presented by the author.

DEPARTMENTAL COSTS IN THE FOUNDRY, by H. B. May, W. K. Henderson Iron Works and Supply Co., Shreveport, La.

REPORT OF COMMITTEE ON FOUNDRY COSTS—presented by W. B. Greenlee, chairman of the committee on foundry costs.

REPORT OF JOINT COMMITTEE OF PATTERN STANDARDIZATION—presented by E. S. Carman, general chairman of the joint committee.

The two reports were accepted as progress reports without special action being taken.

Session No. 11—Malleable Cast Iron

Thursday, Oct. 16, 9:30 a. m.

R. A. Nourse in the chair.

The order of presentation of the papers and reports was as follows:

THE BROADENING OF AN INDUSTRY'S HORIZON, by C. L. Eshleman, Cleveland, Ohio—presented by the author.

REPORT OF COMMITTEE ON SPECIFICATIONS FOR MALLEABLE IRON CASTINGS—presented by Enrique Touceda, chairman of the committee.

POWDERED COAL IN A MALLEABLE CASTING PLANT, by F. L. Wolf and Wm. Romanoff, The Ohio Brass Co., Mansfield, Ohio —presented by Wm. Romanoff.

THE MECHANISM AND GRAPHITIZATION OF WHITE CAST IRON AND ITS APPLICATION TO THE MALLEABLIZING PROCESS, by A. Hayes, W. T. Diederichs, and H. E. Flanders, Iowa State College, Ames, Iowa—presented by Professor Anson Hayes.

Session No. 12—Cast Iron

Thursday, Oct. 16, 9:30 a. m.

Vice-presidjent-elect A. B. Root, in the chair, H. B. Swan, associate chairman.

The papers and reports covering metallurgical and testing phases of cast iron read and discussed were as follows:

MELTING STEEL IN THE CUPOLA, by J. Grennan, University of Michigan, Ann Arbor, Mich.—presented by the author.

REPORT OF COMMITTEE ON CAST IRON—presented by E. J. Lowry, secretary of the committee.

CHILLED CAST IRON, by E. J. Lowry, Hickman Williams & Co., Chicago—presented by the author.

NOTES OF COMPARISON AND STRUCTURE OF A. S. T. M. BAR, by J. W. Bolton, Niles Tool Works, Hamilton, Ohio—presented by the author.

CHARACTERISTICS THAT CHEMICAL ANALYSIS FAILS TO DISCLOSE IN PIG IRON AND CASTINGS, by W. E. Jominy, University of Michigan, Ann Arbor, Mich.—presented by the author.

TESTING IRON TO CONTROL THE PROPERTIES OF CASTINGS, by G. W. Gilderman, Dodge Mfg. Corp., Mishawaka, Indiana—presented by the author.

In presenting the report of the committee on cast iron, Secretary Lowry discussed amendments to the report as printed. After considerable discussion, a motion was made that the printed report should be accepted with the recommended changes as outlined by the secretary and that the report should be forwarded to the Board of Directors for approval.

The amendments to the report of committee on cast iron, presented verbally by Secretary Lowry, were as follows:

1. That the A. F. A. approve the A. S. T. M. Tentative Specifications for Chilled Cast Iron Wheels (A. S. T. M. serial number A46-22T).

2. That the A. F. A. recommend for use as guide in the purchase of pig iron the A. S. T. M. Tentative Specifications for Foundry Pig Iron (A. S. T. M. serial number A43-22T).

3. That the A. F. A. approve the A. S. T. M. Tentative Specifications for High Test Gray Iron Castings (A. S. T. M. serial number A88-22TA).

4. That the A. F. A. approve the A. S. T. M. Specifications for Cast Iron Pipe and Special Castings (A. S. T. M. serial number A44-04).

The Proceedings of the 1924 Convention Banquet

Hotel Pfister, Wednesday, Oct. 15, 7:00 p. m.

The annual banquet of the association in 1924 was held at the Hotel Pfister, Milwaukee, on October 15th. President Gulliam H. Clamer, presiding as toastmaster, began the business of the evening with the following introductory remarks:

Ladies and gentlemen, when I left my home down in Atlantic City to come to this convention, one of my colored maids, a maid who has been in the family for many years, said "Mr. Clamer, I certainly is glad that you got such nice weather for your convention." I said "Aunt Day, the convention is to be held in Milwaukee, and it is to be held next week. Milwaukee is quite a distance off and so is next week," which reminds me of a girl in Allentown. Allentown, as you may know, is in the country Dutch section of Pennsylvania. This young lady was standing on the corner of the street at the time the boys were being mobilized to go into the great war. She said to a bystander, "Why for the soldiers on the street? Why we have a parade today?" "Oh," he says, "Haven't you heard there's a war on?" "War," she says, "it certainly is fine they got such a nice day for it." Now, kind as the weatherman has been to us, our foundry friends here in Milwaukee, and our local committee, have been still more kind to us. They have prepared a program for our entertainment and our comfort and our education which has been magnificent, and I wish to take this occasion to express to them in behalf of our Association, our sincere thanks. I wish particularly to extend our thanks to Mr. Ray Doty, who has had the executive direction of all the committees functioning under the local committee.

We have been in Milwaukee with conventions before. The last time as I recall, was in 1918. I did not, upon that occasion, have an opportunity really to see your city, but through the kindness of Past President Messinger and his good wife, I was

taken about your city on Sunday, and I marveled at its beauty. You really have here a very unique city in that the residential development of the lake front is brought almost into the heart of your city. I am, of course, familiar with the great manufacturing establishments that you have here, and it has been a wonderful opportunity for the American Foundrymen's Association to bring its convention to this city for that reason.

Tonight we are going to have the official presentation of the Penton and Whiting medals. As some of you may have noticed in your schedules of the program sent out, the awards were to have been made at the business session which was held this afternoon. It was thought, however, on further consideration, that this would be the most befitting time to make these formal awards. The choosing of the persons to whom these awards are to be made is in the hands of a Board of Awards. The Board of Awards is made up of the last seven living Past Presidents of the Association.

These awards are being made for the first time. There is, therefore, an added distinction and honor in presenting them to the two men who will be the recipients of these awards upon this occasion. The first award to be made tonight is the Penton award, and I am going to call on the senior Past President to make that award, Mr. Alfred E. Howell.

MR. ALFRED E. HOWELL: *Mr. President, Ladies and Gentlemen and Mr. Touceda*: There are certain milestones in the progress of every institution that deserve to be specially noted. This occasion, the first presentation of the major awards, by the American Foundrymen's Association, is one of them. It must be brief, but hope that I shall not fail to say a few things, appropriate to be said at this time. There are four major awards, as you know, the John A. Penton, the Joseph S. Seaman, the W. H. McFadden and the J. H. Whiting. These four were all pledged at approximately the same time, so that there is no idea of precedence, in the order of their naming. It is due Mr. Penton, to say that he is the man, who first suggested the idea of establishing a fund, the income from which would provide for the perpetuity of these awards, so long as

our association shall continue to exist, which, God grant, may be forever. The record of the past quarter of a century has shown such remarkable advances that no man can foresee what is in store. The incentive for high endeavor is stimulated by the gifts of these generous men.

All of you have seen, or should see, the bronzes, made from the plaster originals by the artist, Mr. Frederick C. Hibbard. The art work is most admirable and the sculptor has caught, what seems to be the dominant note in the character of each donor:

Mr. Penton - - - - - - - - - - - - - - - *Vision*
Mr. Whiting - - - - - - - - - - - - - - - - *Industry*
Mr. McFadden - - - - - - - - - - - - - - *Courage*
Mr. Seaman (our own dear "Daddy" Seaman), *Kindliness*

So, with *Vision* and *Industry*—*Courage* and *Kindliness*, our association cannot fail to continue it career of usefulness, ages after those of us now present—*" like flecks of morning cloud, shall have faded into the infinite azure of the past."* Before presenting this very beautiful medal, provided from the John A. Penton fund, may I remind you briefly of Professor Touceda's achievements, which led to his choice for this particular award by the board of awards. Born in Cuba, about the close of the "period of unpleasantness between our northern and southern states," Enrique Touceda was graduated from the Rensselaer Polytechnic Institute in 1887, at the age of 21, with the degree of Civil Engineer. After several years experience with the Troy Steel and Iron Company, he became their chief chemist and metallurgist. This plant was one of the first to operate under the patents of Sir Henry Bessemer and was built by the eminent engineer, Alexander Holley.

In 1898 Professor Touceda established chemical and physical laboratories in Albany. A few years later he was appointed Professor of Metallurgy at the Rensselaer Polytechnic Institute, which position he now holds in conjunction with his consulting work. In 1912 he became consulting engineer for the American Malleable Castings' Association. It is in this connec-

tion that he has done much of the work for which he is best known. At that time (1912), the quality of malleable iron produced was exceedingly irregular.

Very few companies had sufficiently close control of their processes to produce uniform metal day after day. Professor Touceda devoted himelf to these problems, and to him is largely due the standardization of the analyses and processes which give the best results, and the establishing of the principles, which, if followed would give uniformity of product. "Certified Malleable" became the standard, under Professor Touceda's direction. He also devoted himself to improving the quality as well as the uniformity of malleable. While the requirements of the British Admiralty are high, namely 40,000 pounds per square inch tensile strength and 5 per cent elongation in 2 inches, the requirements of "Certified Malleable" are not less than 50,000 pounds and 10 per cent elongation in 2 inches. This illustrates, briefly, the progress made, which is very largely to be credited to Professor Touceda.

Professor Touceda is a member of numerous scientific bodies, and an honorary member of the Institute of British Foundrymen before whom, in 1922, he delivered the exchange address, representing the American Foundrymen's Association. His work on committees of various technical bodies has been extensive and valuable. It seems, that there is no occasion to explain further the reason for the action of the Board of Awards. I shall ask Professor Enrique Touceda to rise.

(Prof. Touceda rose and was received with applause. Mr. Howell proceeded:)

It is not only in finished undertakings that we honor you, but in the portent of still further achievements. We hope the possession of this beautiful and valuable token, will inspire you to persevere in working out further benefits for mankind. Shakespeare had Mark Anthony say:

"The evil that men do—lives after them,
The good is oft interred with their bones,"

The *good* that you have done will live after you and with cumulative value to human industry. As the years recede, may this "thing of beauty" be indeed a "joy forever" and treasured not alone for its value, but for its significance, conveying as it does the greatest honor that this representative association

AWARD CERTIFICATE PRESENTED TO ENRIQUE TOUCEDA WITH THE JOHN A. PENTON GOLD MEDAL

can bestow upon you. It carries also their hopes for the long continuance in health and happiness and all prosperity, of yourself and of all those whom you hold dear. Professor Touceda,

in behalf of the American Foundrymen's Association, and as determined by the Board of Awards, and acting for them, I present to you, this distinguished honor, the John A. Penton Medal of the American Foundrymen's Association, for the year 1924.

Mr. Touceda then replied as follows:

Mr. Howell, Mr. Chairman, Members of the A. F. A. and Guests:

In accepting this medal, the first John A. Penton award, I am conscious of the very high honor that has been conferred upon me. I am very appreciative of the action of your ex-Presidents in having deemed me worthy of so high a distinction, and I am very grateful to Mr. John A. Penton through whose generosity the award is made possible.

In accepting this medal, Mr. Howell, it is with the thought only that I have simply been made the custodian of a very wonderful and substantial compliment tendered to all those whose efforts have been directed towards the improvement of the malleable iron product, as well as to the industry itself. And now, Mr. Howell, if I could but measure up to the very flattering picture you have drawn of my attainments my contentment would indeed be complete.

I wish to express my sincerest thanks to the officers and other members of the A. F. A. for their kindness to me on this occasion, and to you, Mr. Howell, personally, for your gracious expression of good will.

TOASTMASTER CLAMER: I wish now to call on Past President Major Robert A. Bull, who will make the Whiting Award.

MAJOR R. A. BULL: *Mr. President, Members, and Guests of the American Foundrymen's Association*:

It is characteristic of man to want to honor his fellow man who has developed something of real significance. There are few more pleasant experiences than those we have when giving an expression of appreciation for public service rendered

without a selfish motive. The industrial world presents no exception to this general tendency of human-kind. Contrary to what is pessimistically or egotistically claimed by some who would create distinctions in mental attitude corresponding closely with differences in occupation, I believe that business has a soul, whose manifestations are both visible and inspiring. After more than three decades of intimate acquaintance with foundrymen, I know them to be characterized by loyalty to friends, respect for merit, and the disposition to voice approval or censure with the greatest frankness.

These wholesome traits that typify those who make castings are happily indicated by the present occasion. John Hill Whiting is one of a few members of the American Foundrymen's Association who have, by their splendid generosity, made it possible for this organization to honor publicly those who have signally helped our industry. It has, therefore, come to pass that a group of selected men of experience and mature judgment, as representatives of this large Association, have had their attention drawn to a man who has been a vital force in that branch of the industry to which he has devoted his energies for many years.

The art of making steel castings has, by its fascinating complexities, attracted to it many men of superior intelligence. Its demands on those who serve it have been most exacting. Its contributions to world progress have been, and will continue to be, of the highest importance. The aid thus given modern civilization has been materially increased by him of whom I would now speak.

John Howe Hall was born in 1881, the grandson of Julia Ward Howe and the nephew of Dr. Henry Marion Howe, dean of American steel metallurgists. Mr. Hall's higher scholastic education was obtained at Harvard, where he received the degrees of Bachelor of Arts and Master of Arts. Steel claimed his interest prior to his leaving college, and caused him to select it as the object of a life-long study. Mr. Hall began his career in 1904 by employment with the Bethlehem Steel Company. For two years he acquired experience in the open-hearth department, the puddle mill, the laboratory and the

crucible melting department. Mr. Hall then became a melter for the Buffalo Crucible Casting Company, and later a metallographist for the Taylor-Wharton Iron and Steel Company. In 1911 that company placed him in charge of steel making and heat treatment. During 1913 and part of 1914 Mr. Hall served numerous clients as a consulting engineer. He then became engineer of tests for the Quigley Furnace and Foundry Company. In 1915, Mr. Hall's former employers, the Taylor-Wharton Iron and Steel Company, again secured his services as metallurgist, and retain them today.

Mr. Hall's work has included the development of a heat treated steel containing slightly more than one per cent manganese which has very important properties; the melting of ferro-manganese in the cupola instead of the crucible, which had been used previously; the manufacture of manganese steel in the electric furnace; the investigation of proper heat treatments for, and characteristic physical properties of carbon and alloy cast steels. Mr. Hall's activities have extended for twenty years in the steel branch of the American foundry industry.

There are those who have made important achievements in industry, but who have selfishly, or short-sightedly refrained from doing their part in the interchange of experiences. In marked contrast with this class John Howe Hall has always exhibited a spirit of helpfulness to his colleagues. This tendency is shown by his constructive work as a member of many technical committees, and by his numerous valuable contributions to scienfic literature. These have included many papers for technical societies, including the American Foundrymen's Association. By far the most valuable contribution made by Mr. Hall to others in the steel casting industry is his book entitled "The Steel Foundry," first published ten years ago, and issued in a second edition in 1921. This book is, without doubt, the most valuable guide to better steel foundry practice that has ever been printed in the English language. It, therefore, places its author in that distinguished class which it was Mr. Whiting's desire to honor through carefully considered action by this Association.

In now requesting you, Mr. Hall, to arise, I want to thank you on behalf of the foundry industry for your invaluable part in its development; and to present to you on behalf of the American Foundrymen's Association the first Whiting Medal to

American Foundrymen's Association
INCORPORATED
Through its Board of Directors
Acting upon the recommendation of the Board of Awards
has awarded
THE J. H. WHITING GOLD MEDAL
TO
John Howe Hall
In recognition of his contributions to the Steel Casting Industry.
Annual Convention, Milwaukee, Wisconsin, October 15, 1924.

AWARD CERTIFICATE PRESENTED TO JOHN HOWE HALL WITH THE J. H. WHITING GOLD MEDAL

be conferred on any man, as a tribute from your foundrymen colleagues, and as a public recognition of your splendid share in the development of the art of making steel castings. We are proud thus to honor you. And we trust that with the

passing of years, you and yours may often pleasurably recall this occasion as one significant of the appreciation of your associates, and of the fact that there is a soul in the industry you serve.

MR. JOHN H. HALL: *Major Bull, Mr. Clamer, Members and Guests of the American Foundrymen's Association*: It is hard for me to find words to express my appreciation of the honor which you do me in making me the first recipient of this medal. It is so hard to find words to express my gratitude, that perhaps I'd better let it go at that and not try any longer. It is perhaps fitting for me to think and stop for a moment to consider why these medals are contributed, why they are given. It is not for having ideas, for having knowledge, but for contributing ideas and contributing knowledge that these medals are conferred. Now contributing ideas and knowledge to the industry is first of great benefit to the individual who does the contributing, because others contribute to him, and he learns far more than he gives, many times more. It is also of the greatest benefit to the industry because it encourages all of us to give and to contribute, and for that reason I feel that the greatest honor is due to those who are contributing these medals; they are certainly contributing the most to the development of the industry, far more perhaps than the recipient.

I am very proud to be associated with the steel castings industry, and I know that for some years to come there will be no dearth of recipients of this medal. I have only to look around the room, I had only to attend the sessions of the American Foundrymen's Association today and hear the papers, to realize that the Committee of Awards is going to have a hard time for the next two or three years in selecting the next recipient of this medal because of the many who are worthy of this award. I like to think of the progress we have made in the steel business as a whole in just this matter of contributing information to each other and helping each other and helping the industry.

I remember in 1904 when I was in Bethlehem we wanted to learn something in the foundry, we sent out our best molder.

He was out eight months, and nobody knew where he was, when he came back he had learned how to do the particular thing that he went to learn. We sent out a spy. Here, twenty years later, we have these cooperative groups in the malleable industry and in the steel industry. If we want to know something, we go after the other fellow and we get the information we want because we have helped him. It is great progress, and a most healthy trend in the industry.

We have made great progress in the manufacture of steel castings since the first casting was made in this country in 1867. I remember in 1913 when I went to a meeting of the American Society for Testing Materials and read a paper on the heat treatment of cast steel and told of quenching castings, I got a very cold reception, and one gentleman told me contemptuously that if I had been able to quench a 1,000 pound steel casting without breaking it I was a very fortunate young man. It was a prophetic utterance; I stand here before you today a very fortunate man—perhaps not any longer quite so young a man. Where do we stand today? I saw in the Iron Age last week that a well known steel foundry was prepared to furnish castings with a tensile strength of 100,000 pounds to the square inch, an elongation of 25 per cent and a reduction of area of 50 per cent.

Gentlemen, in 1904, if anyone had said he was prepared to furnish a casting with such physical properties as that, we would have had his sanity examined. Similar steel has been used for the knuckles of freight car couplers, and I am informed that several hundred thousand of those knuckles have been made and used with never a failure. I was proud, as a steel foundryman, to read in Dr. Giolitti's book recently published that in many cases he would far rather have a good casting than a forging for certain classes of service.

We have come a long way in 20 or 25 years, and perhaps the best example of the achievement of the steel foundry industry and of these men who will be the recipients of this beautiful medal which I hold is that during the war and since the war, captains have been content to ride great ships upon cast steel anchor chains, the greatest tribute that I know to the

men who made that steel and to the men who worked out the molding practice by which those chains could be made. Why, when I was a youngster, if you talked of riding a battleship on a cast steel chain—well, I won't say any more.

What of the future? There is going to be a great deal of improvement yet.

We have really only started. They were telling us just the other day of the possibilities of ascertaining whether our castings are perfectly sound by means of magnetic testing and by means of X-rays. Well that is only a start. I heard Dr. Howe a few years before his death, speaking before the American Society for Testing Materials, say that it was not beyond the bounds of possibility that completed structures may some day be tested by the musical note or the wave length of radiation which they give out under certain conditions.

We are going to live to see before a great many years more, almost the perfect steel casting as Kipling visualized the perfect ship, and right today, steel foundrymen, you can make two or three times as good a steel casting as you have ever educated your customers to call for, and as far as I know, as far as I can see, in the next ten years your biggest job is to sell your customers on what you can make and what it is really, in the long run, to your advantage to make. I have been rather long winded, ladies and gentlemen.

When I get on the subject of steel castings, my imagination sometimes runs away with me. I close as I started, with my appreciation of the action of the Medals Awards Committee of the American Foundrymen's Association, in choosing me as the first recipient of this medal.

TOASTMASTER CLAMER: Our Secretary has just handed me a bit of information which is of interest, and which I will pass along to you; that is that our registration up to closing this evening was over 5,000—5,031, including the ladies. This is a record breaker for Milwaukee by over 1,000. I have a telegram here from our dear friend, Mr. Ramas, who, as you probably re-

call, was with us upon the occasion of our banquet and our convention in Cleveland last year. He says:

"The Association Technique de Fonderie sends American Foundrymen's Association best wishes for success of convention and prosperity of Association."

I want to call on Mr. Estep, Chairman of our Committee on International Relations, who will read to you the reply made to that telegram.

MR. H. C. ESTEP: It has become our present custom to exchange greetings once a year with our friends across the sea, and in response to the very generous telegram which Mr. Ramas has sent to us from France and also the telegram which was sent us from the New Castle convention of the Institute of British Foundrymen last June, it has been the pleasure of the Committee on International Relations to contribute the following reply, but before I read it, I just want to say that we are also honored tonight by the presence of the representatives of two of these great foreign Associations, Mr. Ronceray, on my left, representing the Association Technique de Fonderie de France, and Mr. Paul Ropsy, on my right, representing the Association Technique de Fonderie de Belgique; Belgium and France, our two great allies. The cablegram which we sent was as follows:

"The American Foundrymen's Association in annual convention assembled at Milwaukee, Wisconsin, sends greetings to its friends and co-workers across the sea with the hope that the continuance of cooperation between foundrymen internationally may contribute to the advancement of our art and to world peace. We also hope to have you all with us at the International Foundrymen's Congress, which will be held in America in 1926, to which you are all most cordially invited."

TOASTMASTER CLAMER: The choosing of the principal speaker upon this occasion is in the hands of a committee. Very many names were presented for consideration, but the

committee had no trouble in reaching a decision as to who was the proper man to choose and to whom to send the invitation. The committee reached its decision because that man has established a reputation here in the city of Milwaukee where he has spoken before audiences on two occasions previously. They were so well pleased with what he told them and the manner in which he told it to them that they said "By all means we should secure for this occasion as our speaker, Dr. Dyer." We were fortunate, therefore, in having Dr. Dyer accept our invitation to speak to us this evening. Dr. Dyer is Professor of Political Economy in Vanderbilt University at Nashville, Tenn. He has had a year's leave of absence from the University and is now speaking in various parts of the country under the guidance of the National Industrial Council. Dr. Dyer tells me that he has spoken in two or three cities here in Wisconsin recently. Before coming into the banquet I met a friend from Detroit. He had not been fortunate enough or had not secured a ticket to attend the dinner tonight, and he asked me who was going to be our speaker. I told him Dr. Dyer. "Oh," he says, "that is most unfortunate, I certainly am sorry that I cannot be there, but if you have got a balcony I am going to sneak in." I take great pleasure in introducing to you Dr. G. W. Dyer.

Dr. Dyer then delivered an address, The Responsibilities of Leadership Under the Constitution, which concluded the banquet program.

Annual Report of the Board of Directors

To the Members of the American Foundrymen's Association, Inc.
Gentlemen:

We submit herewith for the Board of Directors a report covering meetings of the Board during the year 1924.

The first meeting was held October 12th during the annual convention. The report of the committee to judge competitions for the 1924 Obermayer Prize was received and by vote of the Board the prize was awarded to Herman Honold.

Judges were appointed for apprentice molding contests to be held during convention week.

By unanimous vote of the Board, retiring President Guilliam H. Clamer was recommended for election to honorary membership.

Following a report from H. Cole Estep, Chairman of the Committee on International Relations, the Board voted to go on record in favor of staging an International Foundrymen's Convention in 1926 and that invitations be extended to foundrymen of all countries to attend.

The appointment by the President of a committee of three on Association Policies was authorized.

The next meeting of the Board was held in New York on November 21st. This was the annual meeting. The reports of officers were received.

The special committee on Association Policies submitted a report which was accepted and ordered printed in the Year Book under the caption "Principles of Practice of the American Foundrymen's Association."

Reports were made for the Board of Awards, Executive Committee and special committees. Acting upon recommendations of the Committee on Specifications for Grey Iron Castings, the following A. S. T. M. specifications were endorsed:

Tentative Specifications for High Test Grey Iron Castings, A. S. T. M. serial designation A 88-22T.

Tentative Specifications for Foundry Pig Irons, A. S.

T. M. serial designation A 43-22T.
Tentative Specifications for Cast Iron Car Wheels, A. S. T. M. serial designation A 46-22T.

The report of the special committee on Amendments to By-Laws was received. Following discussion it was voted that the committee be continued and instructed to submit at the next meeting of the Board Amendments to the By-Laws covering entrance fees and dues.

Suitable resolutions were ordered prepared in recognition of the services of past Presidents R. A. Bull and A. O. Backert, who were retiring after having served continuously as Directors since the date of the incorporation of the Association in 1916.

The final meeting of the 1923-24 Board was declared adjourned.

Immediately following adjournment of the old Board, a meeting of the 1924-25 Board was held with President Olson presiding. The Board proceeded to organize by electing Secretary-Treasurer, Assistant Secretary, Manager of Exhibits and Executive Committee.

The recommendations of the Finance Committee for salaries were received and on motion approved.

On a poll of the Directors it was found that a majority believed it would be for the best interests of the Association to hold the 1925 convention and exhibit at some eastern point and the 1926 international convention in the central west. The President was authorized to appoint a committee of five of the Committee on Convention and Exhibits to investigate various cities, and with full power to decide the time and place of the 1925 and 1926 annual meetings.

A form of invitation drafted by the Committee on International Relations to be addressed to foreign foundry associations was read and approved.

The methods of tests adopted by the Joint Committee on Molding Sand Research were tentatively approved for the A. F. A. by the Board.

The recommendations for color markings of patterns adopted by the Joint Committee on Pattern Equipment Standardization were adopted as tentative.

A plan for organizing a joint committee consisting of representatives from various associations for the purpose of studying foundry refractories was approved.

The A. F. A. Committee on Foundry Costs was requested to keep in touch with the activities of other organizations to the end that the members of the A. F. A. might have the advantage of knowing what others were doing.

With this report we show the full minutes of meetings of the Board.

Respectfully submitted,

C. E. HOYT, *Secretary-Treasurer*,

For the Board of Directors.

Minutes of Meetings of Board of Directors

Minutes of Meeting of Board of Directors, American Foundrymen's Association, at Milwaukee Athletic Club, Milwaukee, Wis., Sunday Evening, October 12, 1924.

Following custom, the annual Alumni Dinner of officers, past officers, and honorary members was held at the Milwaukee Athletic Club on Sunday evening of Convention week. The following were present: President G. H. Clamer, Vice-President L. W. Olson, Secretary C. E. Hoyt, Assistant Secretary R. E. Kennedy; Directors A. O. Backert, R. A. Bull, V. E. Minich, C. B. Connelley, A. B. Root, Jr., L. L. Anthes, T. S. Hammond, Alfred E. Howell, C. R. Messinger, Thos. W. Pangborn; members of the Advisory Board, W. R. Bean, Benj. D. Fuller, and H. Ries; Directors-elect A. E. Hageboeck and R. A. Nourse; others by invitation S. T. Johnston, past director and charter member, and H. Cole Estep, Chairman, Committee on International Relations.

Following dinner, President Clamer called the meeting of the Board to order. President Clamer said that before proceeding with the regular order of business, he would like to ask Mr. Allan Ackley, who was waiting outside, to come in and tell those present something about the plans for conducting a membership campaign during Convention Week. Mr. Ackley was invited in and outlined plans for a membership drive, urging the cooperation of all in the plan.

On motion, reading of minutes of meeting of November 20, 1923, was waived.

The chair appointed Messrs. Olson and Root as members of a Committee on Banquet Arrangements, and Messrs. Backert, Bean and Minich, a Committee on Resolutions.

Obermayer Prize

The Secretary read a report from the committee appointed by Mr. Messinger, Chairman of the Board of Awards, to judge entries submitted in competition for the 1924 Obermayer Prize. Their report recommended that the prize be given to Herman Honold, Foundry Superintendent, Worthington Pump & Machinery Corp., East Cambridge, Mass., for a device for making beds for cast iron gaggers and rods.

On motion duly seconded, the recommendation of the judges was accepted and the Chair appointed Mr. Howell as a committee of one to purchase a suitable prize.

Apprentice Contests

The Secretary reported the arrangements that had been made for an Apprentice Molding Contest at the Milwaukee Vocational School, and that it had been requested by those in charge of the apprenticeship program that the Board of Directors name judges for the two contests. For the Grey Iron Contest the Chair appointed Benj. D. Fuller, J. J. Wilson and Pat Dwyer, and for the Steel Contest J. C. Green, W. J. Corbett, R. M. Scott and J. H. Ploehn.

Exchange of Penton Fund Bonds

The Secretary read a communication from the Central National Bank Savings & Trust Co. of Cleveland advising that the Chester Twelfth Company Bonds, Series B, of which the Association owns five $1,000.00 bonds, were being recalled and offering First Mortgage Fee and Leasehold 6% Gold Bonds in exchange, said bonds being secured by a mortgage upon the same property which was covered by the prior mortgage. The

Secretary also read a letter from A. O. Backert explaining this refinancing plan. Upon motion duly seconded, the following resolution was unanimously adopted:

RESOLVED: That the Board of Directors of the American Foundrymen's Association instruct the Harris Trust & Savings Bank to exchange the five $1,000.00 Chester-Twelfth Bonds, Series B, Nos. 66 to 70 inclusive, held in trust by them, for First Mortgage Fee and Leasehold 6% Gold Bonds to the amount of $5,000.00.

PRESIDENT CLAMER ELECTED HONORARY MEMBER

Mr. Messinger moved that the Board of Directors recommend to the members of the Association at the annual meeting on Wednesday, October 15th, that G. H. Clamer, retiring President, be elected to Honorary Membership. Vice-President Olson put the question, which was unanimously carried.

INTERNATIONAL CONGRESS FOR 1926

The Chair called on Mr. Estep, Chairman of the Committee on International Relations, to make a statement concerning the proposed International Foundrymen's Congress. Mr. Estep reviewed the development of international relations between the A. F. A. and similar associations in Europe, resulting in the first International Foundrymen's Congress being held in Paris in September, 1923, and the suggestion which came out of that Congress that the next international meeting be held in America.

Following Mr. Estep's remarks, Mr. Bull moved that the Board go on record in favor of staging an International Foundrymen's Congress in this country in 1926, and that an invitation be extended to foundrymen of all countries to attend. Motion carried unanimously with the recommendation that action taken be reported at the annual business meeting on Wednesday.

1925 CONVENTION

It was duly moved and seconded that the next annual convention and exhibit of the Association be held in the fall of 1925, the time and place to be decided later. Following discussion, the motion was withdrawn with the understanding that the question of next meeting would be considered at the annual meeting of the Board of Directors, which it was voted to hold in New York on Friday, November 21st.

COMMITTEE ON ASSOCIATION POLICIES

The Chair introduced the question of Association policies, reviewing at length questions that had been presented to the Association for action. Discussion was called for, following which the Chair was instructed to appoint a committee of three to consider Association policies and make a report at the annual meeting of the Board.

On motion duly seconded, the meeting adjourned.

Respectfully submitted,
G. H. CLAMER, *President*,
C. E. HOYT, *Secretary*.

Approved November 21, 1924.

MINUTES, ANNUAL MEETING, BOARD OF DIRECTORS, AMERICAN FOUNDRYMAN'S ASSOCIATION, HOTEL ASTOR, NEW YORK CITY, NOVEMBER 21, 1924.

President G. H. Clamer presiding.

The following Directors responded to roll call: L. L. Anthes, A. O. Backert, R. A. Bull, C. B. Connelley, Fred Erb, T. S. Hammond, Alfred

E. Howell, C. E. Hoyt, C. R. Messinger, V. E. Minich, L. W. Olson, Thos. W. Pangborn, and A. B. Root, Jr.; with Directors-elect J. E. Galvin, A. E. Hageboeck, R. A. Nourse and Wm. J. Nugent also present.

Reading of Minutes

Minutes of meeting of November 20, 1923, were read and approved as read.

Minutes of meeting of October 12, 1924, were read and approved as read.

Report of Secretary

The report of the Secretary was read by Mr. Hoyt and on motion was received and ordered filed.

Mr. Howell moved that that portion of the Secretary's report giving the names of individuals largely responsible for the comfort and entertainment of guests at the Milwaukee Convention be transmitted by the Secretary to the various chairmen of Milwaukee committees. Motion prevailed.

Report of Treasurer

The report of the Treasurer was read by Mr. Hoyt and on motion was received and referred to the Finance Committee.

Report of Committee on Association Policies

The regular order of business was suspended and the Chair called for the report of special committee on Association Policies. A. O. Backert, Chairman, reported as follows:

"As enumerated in Article I, Section 2, of the By-Laws of the American Foundrymen's Association, the activities are defined to include the making of investigations and researches, primarily of a technical character, which will advance and promote the welfare of the casting industry. It is within the scope of the activities of the Association to carry on such work as the compilation of cost systems, the making of studies of the apprenticeship problem and similar activities that do not involve a consideration of labor rates and relations. It also is within the scope of the activities of this Association to compile, recommend and adopt standards of practice, singly or in conjunction with other recognized technical societies.

"However, it is not within the activities of the Association to carry out practically the results of its researches and investigations. A cost system, for example, may be recommended for adoption, but its practical installation and application are not within the scope of the Association's activities. Similarly, the results of investigation of apprenticeship systems should be made known to the members and a course of training may be recommended, but its application in individual plants should be left to the foundryman or to the institution that may adopt the apprenticeship system.

"It is not intended that the Association engage in the compilation of so-called trade statistics, such as pig iron production, pig iron stocks in consumers' yards, casting production, etc.

"All partisan controversies are without the scope of the Association, whether of a trade or commercial, political, religious, labor, or any similar nature.

"Nor is it intended that the Association engage in commercial enterprises that in any way will compete with the activities of any of its members.

"A departure from the defined activities of the Association should not be made except in periods of great national or international stress, or following a request from the U. S. Government for aid.

"It is recommended that the foregoing definition and other established practices of the Association be compiled for the guidance of its members. officers and directors and that these be known as the Principles of Practice of the American Foundrymen's Association.

"A. O. BACKERT, *Chairman,*
"L. W. OLSON,
"C. B. CONNELLEY,
Committee."

Mr. Backert moved the adoption of the report. The motion was seconded and following lengthy discussion the report was adopted.

REPORT OF MANAGER OF EXHIBITS

The report of the Manager of Exhibits was read by Mr. Hoyt and on motion was received and ordered filed.

REPORT OF FINANCE COMMITTEE

The Chair announced that Directors Root, Hammond, and Messinger had been appointed as members of the Finance Committee and called for their report, which was presented by Mr. Root, Chairman.

Mr. Root said "The committee considers the duties of the Finance Committee to be the reviewing of the finances, operating expenses and standing of the Association. . . . In reviewing the finances we have made an attempt to formulate a condensed brief statement of the operating expenses of each individual department. . . . We will not burden you with all of the figures which substantiate those presented in the Treasurer's report. All you are interested in are conclusions and recommendations."

(Mr. Root presented figures showing the financial condition of both technical and exhibit departments as of date of November 15th and estimated expenses and financial condition at the end of the year. These figures are omitted here, as with this report will be printed the auditor's report as of December 31st, setting forth the true condition of Association finances.)

Mr. Root moved the acceptance of the report and the consideration immediately following of the recommendations of the committee. Motion prevailed.

Recommendation No. 1

The committee recommends that the technical funds be reimbursed for research expenses during 1924 by a transfer of $1,500.00 from the exhibit fund. On motion, the recommendation was adopted and the transfer ordered.

Recommendation No. 2

The committee recommends the usual transfer for technical expenses, the sum of $1,000.00 from the exhibit fund. On motion, the recommendation was adopted and the transfer ordered.

Recommendation No. 3

The committee recommends that the Directors authorize a budget for research work to the amount of $2,500.00 during the year 1925. Following discussion it was voted to authorize this expenditure from the reserve fund, if, in the judgment of the Executive Board, expenditures for research work to that amount were justified.

Recommendation No. 4

The committee recommends that C. E. Hoyt, Manager of Exhibits, be paid from exhibit funds a provisional additional compensation of

$1,000.00. On motion, the recommendation of the committee was authorized.

Recommendation No. 5

The committee recommends that Assistant Secretary R. E. Kennedy be paid from surplus an additional compensation of $500.00. On motion, the recommendation of the committee was authorized.

Recommendation No. 6

The committee recommends that a donation of $250.00 from exhibit funds be made to the Institute of Metals Division of the A. I. M. E. On motion, the recommendation of the committee was authorized.

Recommendation No. 7

The committee recommends the purchase of $4,000.00 par value U. S. Liberty Loan 4¼% bonds, to be added to the reserve fund, and that on or about June 1, 1925, an additional $500.00 bond be purchased from income from the reserve fund and added to the reserve. On motion, the recommendation of the committee was approved and the purchase of the bonds ordered.

REPORT OF BOARD OF AWARDS

The Secretary read for the Board of Awards a report reviewing the activities of committees of the Board during the past year and the awarding of the John A. Penton Medal to Enrique Touceda and the J. H. Whiting Medal to John Howe Hall, presentation being made at the annual banquet during convention week at Milwaukee.

The report showed that disbursements, including cost of designs, dies and medals, totaled $2,994.00, leaving a balance in the Award Interest Fund as of date of November 15th of $401.22.

The report carried the recommendation that suitable resolutions be authorized by the Board as an appreciation of the very satisfactory work done by Frederick C. Hibbard, sculptor.

On motion, the report of the committee was accepted and the recommendation that resolutions be prepared approved.

It was moved that the Secretary be authorized to have bronze replicas of the medals framed in plush cases and displayed in the office of the Association. Motion prevailed.

EXECUTIVE COMMITTEE

The Secretary, reporting for the Executive Committee, stated that no meetings had been held during the year and that all the work of the committee had been conducted by correspondence.

SPECIAL COMMITTEES

The Secretary read a summary of reports of special committees prepared by Assistant Secretary R. E. Kennedy. The report was accepted and the Board took under consideration those committee reports requiring action.

SPECIFICATIONS FOR GREY IRON CASTINGS

When this report was taken up, Mr. Walter Wood, who came into the meeting at this time, requested an opportunity to say a word about the report of this committee. Mr. Wood, although not a member of the committee, had attended meetings and taken an active interest.

In the absence of a report of the session at which the report of the committee was presented at the Milwaukee Convention, Mr. Wood explained that the printed report submitted was supplemented by a verbal

report of recommendations approved by the committee at a session held the previous day.

As there was some doubt as to what the verbatim report of the grey iron session would show, it was moved that when the Secretary had this report and had corresponded with the Chairman and Secretary of the Committee, that he prepare the recommendations for approval by the Board members by letter ballot, and that the result of the letter ballot be incorporated in the minutes of this meeting. Motion seconded and carried.

These instructions were carried out and the following recommendations were submitted to the Board for letter ballot and approved by them:

(a) Recommendation that the A.F.A. endorse the A.S.T.M. tentative specifications for High Test Grey Iron Castings, (A.S.T.M. serial designation A88-22T).

(b) Recommendation that the A.F.A. endorse as a guide for the purchase of pig irons the A.S.T.M. tentative specifications for Foundry Pig Iron (A.S.T.M. serial designation A43-22T).

(c) Recommendation that the A.F.A. endorse the A.S.T.M. tentative specifications for Cast Iron Car Wheels (A.S.T.M. serial designation A46-22T).

(d) Recommendation that a committee or sub-committee be formed to study the subject of quality of pig iron with a view to ascertaining the qualities which represent a good pig iron.

At this point a recess was taken until 2:00 P. M., when the meeting was again called to order with President Clamer in the Chair.

Amendments to By-Laws

R. A. Bull, Chairman of the special committee on Amendments to By-Laws, submitted a report proposing amendments to Article II re Membership Classifications, and Article VIII re Fees and Dues. Mr. Bull stated that inasmuch as the report proposed some decided changes in the By-Laws, he regretted very much that he had been unable to get copies into the hands of the Directors before the Board meeting, that each might have had an opportunity to consider them. Mr. Bull stated further that he would not like to see any proposed amendments adopted at this meeting, unless there was unanimous sentiment in favor of adoption.

A lengthy discussion ensued, participated in by all Directors present. It was the consensus of opinion that amendments to the By-Laws along the lines proposed would be beneficial to the Association. It was the feeling, however, that the report should be given further thought.

On motion, the report was referred back to the committee to be revised in accordance with the majority opinion expressed and reported back to the Directors at the next meeting of the Board.

Resolutions

Director Root asked the privilege of the floor and spoke as follows: "The Board is about to lose as one of its members, upon the retirement of this Board, our good friend Major Bull, who has served the Association faithfully as an official for fourteen years. His retirement should not pass without recognition and I move that the Chair appoint a committee of one to draw up resolutions upon his retiring."

The motion was unanimously adopted and the Chair appointed Alfred E. Howell as a committee of one to draw up the resolutions and present them for approval at some future time.

Director Hoyt asked the privilege of the floor and spoke as follows: "In looking over the list of retiring Directors, I note there is another who has served the Association faithfully and I move that Mr. Howell be instructed to prepare suitable resolutions for our good friend A. O. Backert, who is leaving the Board today after having served the Association first as Secretary and then as President. He was also one of the organizers of the A.F.A., Incorporated, and has been a Director since 1916." Motion seconded and carried unanimously.

REPORT ON ELECTION OF OFFICERS AND DIRECTORS

The Secretary reported that at the annual business meeting of the Association, October 15, 1924, it was reported that the Nominating Committee had nominated the following for Officers and Directors of the Association for the year 1924-1925:

For President to serve for one year: L. W. Olson.
For Vice-President to serve for one year: A. B. Root, Jr.
For Director to serve for one year: V. E. Minich.
For Directors to serve for three years: G. H. Clamer, John E. Galvin, A. E. Hageboeck, R. A. Nourse and Wm. J. Nugent.

It was further reported that these nominations had been submitted to the members by mail on July 7th and that inasmuch as there had been no further nominations, it would be in order for the members present, acting in accordance with Article X, Section 1, of the By-Laws, to declare the members whose names appeared in the report of the Nominating Committee as duly elected for the offices for which they were nominated, the terms of office to begin at the annual meeting of the Board of Directors, which, in accordance with the By-Laws, shall be held within ninety days of the closing date of the annual meeting. On motion duly seconded, the Secretary was instructed to cast the unanimous ballot of the members present for the ticket presented by the Nominating Committee.

President Clamer: "You have heard the report. Is there any further business? If not, I desire to express my earnest and sincere thanks for the very hearty cooperation of all the members of the Board, of the Secretary, and the other officers of the Association. In the words of our Milwaukee friend, it has really not been a job but a pleasure to me, I assure you.

"I desire to express to President-elect Olson and the new Board the wish for a successful year and to assure them that they can at any time call on the retiring members for assistance. This meeting will now stand adjourned and I will turn the gavel over to President Olson, who I understand will immediately call the meeting of the new Board to order."

Respectfully submitted,
G. H. CLAMER, President.
C. E. HOYT, Secretary.

MINUTES, FIRST MEETING, 1924-25 BOARD OF DIRECTORS, AMERICAN FOUNDRYMEN'S ASSOCIATION, HELD AT HOTEL ASTOR, NEW YORK CITY, NOVEMBER 21, 1924. PRESIDENT L. W. OLSON PRESIDING.

President Olson in accepting the gavel from retiring President Clamer called the meeting of the new Board to order and said, "Gentlemen: I am not going to make a speech. We are pressed for time and I think we ought to get after the things that are ahead of us. I only wish to say

that I will endeavor to do as well as I can and while it becomes increasingly difficult to make a showing because of the past record of this Association and its Board, I will do what I can to keep up the traditions."

The Chair instructed the Secretary to call the roll, which showed the following Directors present:

L. L. Anthes, G. H. Clamer, C. B. Connelley, Fred Erb, A. E. Hageboeck, T. S. Hammond, Alfred E. Howell, C. E. Hoyt, C. R. Messinger, V. E. Minich, R. A. Nourse, Wm. J. Nugent, Thos. W. Pangborn, and A. B. Root, Jr. Retiring Directors A. O. Backert and R. A. Bull were also present.

Election of Officers

The Chair announced that the first order of business would be the election of Officers and called on Mr. Clamer, Chairman of the Nominating Committee.

Mr. Clamer: "Your Committee on Nominations begs leave to report as follows:

For Secretary and Treasurer—C. E. Hoyt.
For Manager of Exhibits—C. E. Hoyt.
For Assistant Secretary—R. E. Kennedy.
For Members of Executive Committee—T. S. Hammond, R. A. Nourse, Wm. J. Nugent, and Thos. W. Pangborn.

Chairman: "You have heard the report of the committee. What is your pleasure? If you have no objection, we will take each office separately."

It was moved that the office of the Secretary-Treasurer be combined, as provided for in Article III, Section 1, of the By-Laws. Motion prevailed.

It was moved that the unanimous ballot of the Board be cast for C. E. Hoyt as Secretary-Treasurer. Motion prevailed.

It was moved that the unanimous ballot of the Board be cast for Robert E. Kennedy as Assistant Secretary. Motion prevailed.

It was moved that the unanimous ballot of the Board be cast for C. E. Hoyt as Manager of Exhibits. Motion prevailed.

The Chair called for further nominations for the Executive Committee. There being none, it was moved that the unanimous ballot of the Board be cast for the nominees, T. S. Hammond, R. A. Nourse, Wm. J. Nugent and Thos. W. Pangborn. Motion prevailed, whereupon the Chair declared that these four, together with the President, Vice-President and Secretary, would constitute the Executive Committee of the Board for the ensuing year.

Mr. Clamer moved that the Executive Committee be empowered to act for the Board in the interim between Board meetings in all matters requiring Executive action. Motion prevailed.

Report of Finance Committee

The Chair called for the report of the Finance Committee. Mr. Root, Chairman of the Finance Committee, submitted the following recommendations:

(a). Salary of C. E. Hoyt as Secretary-Treasurer—$2,400.00.
(b) Salary of C. E. Hoyt as Manager of Exhibits—$7,600.00.
(c) Salary of R. E. Kennedy as Assistant Secretary—$3,600.00.
(d) Salary of Miss Jennie Reininga as Assistant to C. E. Hoyt—$225.00 per month, $75.00 to be paid from the technical fund and $150.00 from the exhibit fund, effective as of January 1, 1925.
(e) The President and Secretary be authorized to employ such office assistants as are necessary to take care of Association activities.

(f) Separate from technical department all expenses for purely research work, account to be known as technical account research account.

(g) The committee approves of the separation of the expenses of Association work into department accounts as a guide for the conduct of its business.

(h) To permit annual comparisons of operating expenses, the committee recommends that the reports of future Finance Committees be made upon the basis of this report.

On finishing the report, Mr. Root proceeded to move the adoption of each item in the order listed, whereupon each motion was duly seconded and carried.

Disbursement of Funds

Resolved, That L. W. Olson as President and C. E. Hoyt as Secretary-Treasurer, be authorized to sign checks and draw against funds deposited in the Harris Trust & Savings Bank, Chicago, Standard Trust & Savings Bank, Chicago, and the Central National Bank Savings & Trust Co., Cleveland, Ohio, in the name of the American Foundrymen's Association, Inc.

Be It Further Resolved, That the resolutions required by the banks authorizing withdrawal of funds are hereby approved and adopted.

Resolved, That the President and Secretary-Treasurer be authorized to make the necessary arrangements for a special convention fund and maintain a Secretary-Manager's petty cash fund of $500.00, said fund to be reconciled at the end of each month with full statement of expenditures.

On motion the resolutions were unanimously adopted.

Time and Place of 1925 Convention

The Secretary reported that at the annual convention invitations from the various cities were reported and on motion these were referred to the Board of Directors for their consideration and action. The Secretary then read the invitations from a number of cities, supplementing them with such information as he had at hand as to conditions prevailing in each city.

Following the Secretary's presentation, the members were invited to give their views. It appeared to be the unanimous opinion of those present that the logical place for the 1925 convention and exhibit was in some eastern city, and that the central west would be the logical place for the 1926 international Foundrymen's Congress.

The Secretary stated that it was customary to appoint a Convention and Exhibits Committee of seven or nine members, and to appoint five members of this committee as a special committee to investigate conditions and determine the place and time of meeting.

Mr. Root moved that the Chair appoint a committee of five to consider the invitations and with authority to determine the time and place of the 1925 and 1926 conventions and exhibits. Motion seconded and unanimously adopted.

Invitations to International Foundrymen's Congress

The Secretary presented on behalf of Mr. Estep, Chairman of the Committee on International Relations, a form of invitation to be sent to foundry organizations in foreign countries. Mr. Clamer moved that the committee be authorized to prepare and extend, on behalf of the American Foundrymen's Association, an invitation to the International Foundrymen's Congress after the time and place of said Congress had been determined. Motion prevailed.

Illuminated Resolutions

The Secretary reported receipt of letters from foreign organizations expressing appreciation of illuminated resolutions received from the A.F.A. Several of these letters were read.

The Secretary reported that the Association Technique de Fonderie de France were in session at this time and proposed a message be sent to them. It was moved that Mr. Clamer be instructed to cable greetings from the Board to the French Association. Motion prevailed.

Adoption of Methods of Sand Tests

The Secretary brought up the question of adoption by the Board of the tentatively adopted methods of tests of the Joint Committee on Molding Sand Research. The Chair requested Major Bull to present the matter to the Directors. Major Bull said:

"I think the Association should give its official endorsement in a tentative way to what the Joint Committee has already adopted as tentative. This Board could not adopt it as a standard without the formality of having it first endorsed at a members' session, but the Board could, and I think should, tentatively adopt for the Association these methods which have been adopted by the committee and promulgated through the medium of a pamphlet issued by the Association."

Mr. Clamer moved the adoption as tentative by the Board of the methods of tests adopted by the Joint Committee on Molding Sand Research. Motion seconded and carried.

Tentative Adoption of Recommendations for Color Markings of Patterns

The Secretary gave a summary of the report of progress for the Joint Committee on Pattern Equipment Standardization, stating that the committee recommends to the Board of Directors for adoption the color marking standards as approved by the Joint Committee.

Mr. Connelley, Chairman of the members' session at the Milwaukee Convention at which the report was made, stated that no action had been taken by the members and therefore it would not be in order for the Board to adopt the markings as A. F. A. standards. Several members spoke as to the value of the work this committee was doing.

Mr. Howell moved that the Board adopt as tentative the recommendations of the committee for color marking of patterns. Motion seconded and carried.

Report of Refractories Committee

The Secretary presented a report for the Committee on Refractories. The report stated that there were a number of committees functioning on about the same lines as the Refractories Committee of the A. F. A. and to avoid duplication of work, the committee desired the approval of the Board to approach other societies interested in refractories in the forming of a joint committee to study foundry refractories. The report stated further that the committee hoped to have the American Ceramic Society sponsor the work.

On motion, the proposed activities of the Committee on Refractories were approved.

On motion, the President was authorized to name an A. F. A. representative on the Committee on Safety Code for Machinery for Compressing Air, sponsored jointly by the American Society of Safety Engineers and the American Society of Mechanical Engineers.

Convention Badge for Honorary Members

It was moved by Mr. Root that the Board refer to the Committee on Convention and Exhibits, with power to act, the question of providing a distinctive badge at the convention for honorary members. Motion seconded and carried.

Foundry Costs

The Secretary brought up the question of foundry costs and suggested that Mr. Hageboeck, a member of the committee, give the Directors his views on the subject. A lengthy discussion followed Mr. Hageboeck's remarks. All were agreed as to the importance of this work but felt that it was not within the province of the A. F. A. to do more than to carry on educational work in conjunction with other interested organizations.

Mr. Hammond moved that it was the sense of the Directors that the Association was interested in cost work and that the committee be asked to continue their efforts and work with the National Founders Association and others to the end that the members of the A. F. A. might receive the benefit of work that others were doing and further, that if the committee found that an appropriation of funds was needed, they could ask for it later. Motion seconded and carried.

Directors' Meeting Expense

Mr. Clamer moved that 50% of the expense of this meeting be paid by the technical department and 50% by the department of exhibits. Motion seconded and carried.

There being no further business, the Chair declared the meeting of the Board adjourned.

Respectfully submitted,

L. W. Olson, *President*,

C. E. Hoyt, *Secretary*.

Report of Manager of Exhibits for the Year Ending December 31, 1924

Covering 18th Annual Exhibit, Milwaukee, October 11 to 16, 1924

The following is submitted as a brief report of the eighth exhibit held under the auspices of the A. F. A. and the 18th held in conjunction with the annual conventions of this Association. This exhibit, which was held in Milwaukee Auditorium, Milwaukee, Wisconsin, was formally opened at 1:00 P. M., Saturday, October 11, continuing through until 10:00 P. M. Saturday was advertised and known as Milwaukee Day and free admission tickets were distributed to employees of the metal manufacturing industry through employers in the Milwaukee district.

The exhibit was closed Sunday and open from 8:30 A. M. to 5:30 P. M. from Monday to Thursday inclusive. This was the second successive year for a Saturday opening. The plan has many advantages over a Monday opening and it is felt should be followed whenever practicable.

In accordance with the plan approved by the Board of Directors, admission to the exhibits was by badge obtained upon registering. No registration fee was charged members of the Association. A charge of $1.00 was made to all extra representatives, exhibitors' representatives, and guests. A special registration was provided for those who wished to visit the exhibit only once, or who were not associated with the foundry industry. A charge of 50c was made but no badge provided. Special tickets were given and taken up at the door. Tickets were not required of those wearing a convention badge. This plan was generally accepted as an improvement over the paid admission plan and is recommended for future conventions.

Two hundred and eighteen firms paid the exhibitor's permit fee and 212 had exhibits. Of this number 72 did not exhibit at the Cleveland Convention the previous year. The total number of exhibits was two less than in 1923. The total space sold was 55,165 square feet, 8,110 square feet in excess of that sold at Cleveland. The average price of space was 77.4c per square

foot, as against an average price of 77.8 cents per square foot at Cleveland.

As the principal income from exhibits is derived from space sold on a square foot basis, it is customary to figure costs on a square foot basis. It is interesting to note how consistently these costs average. Take for instance the question of booths and decorations. For the four years 1919 to 1923, the amount of space occupied varied from a minimum of 46,787 square feet to a maximum of 76,600 square feet. The difference between the minimum and the maximum costs for four years was only 89 cents per square foot. Favorable conditions at Milwaukee made it possible to keep the cost 2.02 cents below the average cost of the previous four years. On the other hand, conditions were such that the cost of power at Milwaukee was $1966.20 greater than at Cleveland.

The auditor's report for the year ending December 31, 1924, is a consolidated one including all Association activities. The funds of the department of exhibits, however, are kept in a separate account. We had cash on hand January 1, 1924, $2044.59 and cash on hand December 31, 1924, $2974.40. We added during the year $4000.00 to our reserve fund, making the total set aside for reserve during the past six years $20,592.17. This sum is invested in U. S. Liberty Bonds, par value $22,000. The reserve fund now represents about 60% of the average cost of a year's operations of the department of exhibits.

The wisdom of creating a reserve fund can be readily seen when we take into consideration that the exhibitor has no financial responsibility and could not be assessed in the event of any unexpected or unusual situation which would result in a deficit. Neither could the members of the Association be assessed. Therefore, the only safeguard is either in carrying liability insurance or establishing a reserve fund.

The Milwaukee Auditorium with its exhibition halls, convention halls, dining rooms, committee rooms, etc., offers unusual accommodations for a combined convention and exhibit. The Auditorium is efficiently managed and in closing this report we wish to express appreciation of the courteous treatment and assistance rendered at all times by the Manager, Joseph C. Grieb and his staff.

Respectfully submitted,

C. E. Hoyt, *Manager of Exhibits.*

Annual Report of Secretary-Treasurer

To the President and Members of the American Foundrymen's Association, Inc.

Gentlemen:

There is a degree of satisfaction in reviewing the work of the Association for the past year, not because of growth in numbers, for we have had better years, nor because of financial showing for we ran far behind previous years in our finances, but in the volume and quality of our technical output we did excel. We had the largest, and by many considered the best, convention ever held. Our committees, larger in number and in personnel, did much constructive work. None of their reports were final and with a few changes and some additions they will carry on during 1925. The bound volumes of Proceedings for 1924 will contain over 1200 pages, 50% greater than any previous year.

We now have, in addition to our general section, four distinct sections or group activities. They are grey iron, steel, malleable and non-ferrous. Our conventions are like a three or four ring circus and with our large and instructive exhibit, plant visitation, etc., the annual Foundrymen's Week in America, under the auspices of the A. F. A., is the most important event of the year in the advancement of the foundry industry.

In accordance with custom we submit herewith a report on membership and finances:

Membership

Our book membership on January 1st, as shown in our last report, was 1560. New members were added each month, the smallest number being five. The largest month was October with 58. The total of new members elected during the year was 177. We received 79 resignations, nearly all from individuals retiring or firms going out of business. Thirty-six were dropped as delinquent, one removed by death. The total lost was 115, net gain 62, or 4%. This was a disappointment, as we had hoped

to increase our gain of 7% the previous year. The book membership on December 31st was 1622.

Finances

The auditor's statement shown with this report is a combined statement of all Association activities, technical and exhibit. The excess of income over expenses is given as $4905.46.

The technical department expenses, however, were exceptionally heavy, being $4849.17 greater than in 1923. Three items alone, publications, printing and postage, represent an increase of $2949.94. Increased technical and editorial salaries and convention expense amounted to $1704.67. All of these excess expenses as enumerated above are accounted for in our approximate 50% increase in technical activities.

The cost per member in 1922 was $13.17, in 1923 $13.66, and in 1924 the cost jumped to $16.13 per member, an increase of $2.75 over the average of the two previous years. With dues at $12.00 per annum, it will be readily seen that a serious deficit would occur if it were not for income from entrance fees, sale of publications and transfers from earnings of the department of exhibits. The amount transferred in 1922 to support technical work was $3000.00, in 1923—$3000.00, and in 1924—$2500.00.

We believe all technical activities of the Association should be self-supporting from dues, fees and subscriptions. To accomplish this would mean one of three things; first, limit our activities, which we do not believe desirable; second, increase our membership to a point where it would absorb the overhead; and third, increase dues. The time has arrived when it will be necessary for the Board of Directors and the members to consider plans for meeting the increased expense of operation due largely to increased cost of printing and greater activities.

Research Funds

On December 31st we had $1163.90 in what is known as the Cleveland Research Fund, $520.25 in the Rogers Brown Fund, and $2552.83 in a special sand research fund. Individual

contributions to sand research since our last report were as follows:

George F. Pettinos	$300.00
Whitehead Bros. Co	500.00
Ayers Mineral Co	200.00
Institute of Metals Div., A. I. M. E.	100.00

As a further recognition of the splendid work of this committee, the Board of Directors voted to contribute the sum of $5000.00 from its reserve fund, making the total contributions for the year $6100.00. The budget of the Joint Committee on Molding Sand Research calls for an expenditure of approximately $5000.00 during the coming year.

Awards Funds

The expenses of the year, including designs, models, dies, medals, etc., for awards was $2994.00. On December 31st there was a balance of $462.88 in the awards income fund. This, of course, is in excess of the principal of $21,000.00 which, in accordance with the terms of gift, must be kept intact.

In the auditor's statement which follows Exhibit B is shown as a summary of the transactions affecting the various funds for the year, and Exhibit C is a statement of income and expenses of the technical and exhibit departments, for the year.

In President Clamer's annual address, in the summary of Convention Week, in the report for the Directors and the Manager of Exhibits, the work of the Association is further reviewed, and in the bound volume of Proceedings the year's accomplishments will be recorded.

We desire to acknowledge with sincere appreciation the co-operation of all authors of papers and reports, committee members and others who have contributed to the success of the Association. For the support of President G. H. Clamer, Vice-President L. W. Olson, the Board of Directors, Assistant Secretary R. E. Kennedy and the co-operation of all the staff, we express warmest appreciation and thanks.

Respectfully submitted,

C. E. Hoyt, *Secretary-Treasurer.*

Auditor's Report

CHICAGO, JANUARY 10, 1925

Mr. L. W. Olson, President,
American Foundrymen's Association, Inc.,
Chicago.

Dear Sir:

In accordance with your instructions, we have audited the books and accounts of the American Foundrymen's Association, Inc., for the year ended December 31, 1924, and now submit our report thereon, accompanied by the following statements:

Balance Sheet as at December 31, 1924	Exhibit A
Statement of Funds as at December 31, 1924	Exhibit B
Statement of Income and Expenses for the year ended December 31, 1924—General Fund	Exhibit C
General Fund Surplus as at December 31, 1924	Exhibit D
Reserve Fund Surplus as at December 31, 1924	Exhibit E
Research Fund Accounts as at December 31, 1924	Exhibit F
Award Funds Surplus as at December 31, 1924	Exhibit G
Securities—December 31, 1924	Schedule I

Balance Sheet

The financial conditions of the Association as at December 31, 1924, is presented in the accompanying Balance Sheet, Exhibit A, which has been drawn up to show the status of the various funds at that date.

The cash on deposit in banks was verified by certificates obtained from the banks and a reconciliation thereof with your cash records.

The accounts receivable, which represent unpaid dues and power accounts are considered good. During the year accounts considered uncollectible, amounting to $813.00, were written off.

The furniture and fixtures account represents the book value of these assets, less depreciation which we have written off at the rate of 10 per cent per annum.

Securities owned, which are held by the Harris Trust & Savings Bank, Chicago, for safe-keeping, were verified by certificates obtained from the bank. The securities are listed on Schedule I.

The amount due Research Funds from the General Fund, $2,552.83, represents the unused balance of donations received for sand research, which is carried on the books as part of the General Fund. The amount due from Reserve Fund, $2,500.00, is an appropriation authorized in November, 1924, to be transferred from the Reserve Fund for General Research purposes.

Statement of Funds

The Statement of Funds, Exhibit B, summarizes the transactions of the year affecting each of the several funds and shows the resulting bal-

ances as at December 31, 1924. The total surplus in all funds amounted to $51,417.91. The details of the various Surplus Accounts are shown in Exhibits D, E, F, and G. The total income of all funds for the year amounted to $74,047.94, while expenses of all funds were $72,558.99.

Statement of Income and Expenses—General Fund

A classified Statement of the Income and Expenses of the General Fund for the year ended December 31, 1924, is shown on Exhibit C. The total income for the year amounted to $71,025.22, while the expenses were $66,119.76. The excess of income over expenditures, amounting to $4,905.46, has been credited to the General Fund Surplus.

Certificate

We have examined the books and accounts of the American Foundrymen's Association, Inc., for the year ended December 31, 1924, and

WE CERTIFY that the Balance Sheet, Exhibit A, has been correctly prepared from the books and, in our opinion, presents the true financial condition of the Association at December 31, 1924, and that the Statement of Funds, Exhibit B, is a correct summary of the transactions affecting the various funds for the year ended at that date.

Respectfully submitted,

JOHN K. LAIRD & COMPANY,

Certified Public Accountants.

Exhibit B

AMERICAN FOUNDRYMEN'S ASSOCIATION, INC.

Statement of Funds as at December 31, 1924

	General Fund	Reserve Fund	Cleveland Research Fund	Sand Research Fund	General Research Fund	Rogers Brown Fund	Award Funds	Total
Fund Balances, Dec. 31, 1923, per Audit Report	$ 8,347.75	$16,932.84	$1,118.72	$ 101.94	.....	$505.00	$23,376.59	$ 50,178.96
Add or *Deduct:* Adjustments of Surplus	5,000.00	.....	.....	5,000.00	.....	.....	.....	.....
Adjusted Surplus Balance, Dec. 31, 1923	$ 3,347.75	$16,932.84	$1,118.72	$4,898.06	.....	$505.00	$23,376.59	$ 50,178.96
Income, Year Ended Dec. 31, 1924	71,025.22	782.00	45.18	1,100.00	.....	15.25	1,080.29	74,047.94
	$74,372.97	$17,714.84	$1,163.90	$5,998.06	.....	$520.25	$24,456.88	$124,226.90
Expenses, Year Ended Dec. 31, 1924	66,119.76	.....	.....	3,445.23	.....	.....	2,994.00	72,558.99
	$ 8,253.21	$17,714.84	$1,163.90	$2,552.83	.....	$520.25	$21,462.88	$ 51,667.91
Add or *Deduct:*								
Net Fund Transfers	3,000.00	500.00	.....	.....	$2,500.00	.....	.....	.....
Donation to A. I. M. E.	250.00	.....	.....	.....	.....	.....	.....	250.00
Fund Balances, Dec. 31, 1924	$ 5,003.21	$18,214.84	$1,163.90	$2,552.83	$2,500.00	$520.25	$21,462.88	$ 51,417.91

Exhibit C

AMERICAN FOUNDRYMEN'S ASSOCIATION, INC.

Statement of Income and Expenses
For the year ended December 31, 1924
General Fund

Income			
Space Rental		$42,731.00	
Dues and Subscriptions		19,227.67	
Exhibitors' Permits		5,450.00	
Registration Fees		3,312.00	
Interest on Bank Deposits		304.55	
Total Income			$71,025.22
Expenses			
Salaries—Manager of Exhibits	$ 7,600.00		
Secretary and Assistant Secretary	5,750.00		
Clerical and Stenographic	5,901.00	19,251.44	
Convention Expense:			
Department of Exhibits	$15,003.63		
Technical Department	1,337.37	16,341.00	
Publications		9,967.90	
Advertising (Exhibit)		5,555.77	
Printing and Stationery		3,297.47	
Committee Travel and Expense		3,311.05	
Postage		1,956.83	
Office Rent		1,441.00	
Membership Campaign Expense		1,438.97	
Office Expense:			
General	$ 596.87		
Telephone and Telegraph	427.63		
Auditing	275.00		
Dues, other Associations	51.00		
Taxes	11.88	1,362.38	
Traveling Expenses, Manager and Assistants		1,154.86	
Bad Accounts written off		813.20	
Depreciation on Furniture and Fixtures		134.58	
Bank Exchange		93.31	
Total Expenses			66,119.76
Excess of Income over Expenses for the year ended December 31, 1924			$ 4,905.46

Annual Address

By the President, Guilliam H. Clamer

Our Association was organized in my native town, the city of Philadelphia, in 1896. The men who organized the Association had surprising vision and a comprehensive understanding of the needs of our industry. At that time but little real technical knowledge had entered the industry. Pig iron in this country was still sold on fracture. Steel foundries were practically in their infancy as we know them today. Malleable iron was a product of mystery, and in the non-ferrous industry the chemist had not yet entered. I became associated in the brass foundry industry two years after the organization of the American Foundrymen's Association. In so far as I am able to learn, I was the first chemist to become regularly connected with a brass foundry. The great wrought brass industry of our country had not a single chemist at that time. The aluminum casting industry as such was not in existence. The few aluminum castings made were made in the brass foundry.

The following was stated by the organizers of our Association to be the objects of the same:

(1) To conduct research activities which were too extensive or too costly for any except the large organizations to conduct independently.
(2) To act as a clearing house for foundry information and the advanced ideas of practical foundrymen.
(3) To act as a proper representative in matters of industrial relations affecting the industry.
(4) To sponsor foundrymen's conventions and exhibits and other meetings of foundrymen having the betterment of the industry as an objective.

The World's Foundry Associations

A review of the organized activities of the various foundry associations in the world reveals the following facts: There are more than twenty associations devoted to work of dissemi-

nating technical information on foundry subjects. All these associations hold meetings for that purpose. Our own Association holds the honor of having been the first in the field and also the largest now in existence. The French, Belgium and German Associations are conducted along lines very similar to our own. The Institute of British Foundrymen, however, has evolved its own organization, taking as its model the old engineering societies. Its membership is limited to workers in the foundry field. The British Institute of Foundrymen admits no foundry supply or equipment firms or their representatives as such. It is precluded from organizing exhibitions by its royal charter. The Swedish, Dutch, Norwegian and Italian associations are primarily employer's associations. They do, however, discuss technical subjects.

Scope of American Foundrymen's Association

There has been a feeling on the part of many that our Association should be restricted in its field of activity to the truly technical, and that all other subjects should be eliminated. We have thus far, however, followed in general the policy as set forth by our organizers, namely:

(1) We conduct research.
(2) We regularly hold sessions for the presentation and discussion of technical papers, and through the medium of our Bulletin we disseminate information of value to the industry.
(3) We hold sessions for the discussion of industrial relations.
(4) We hold exhibitions.
(5) Cost finding, Industrial Education, etc.

We are constantly receiving invitations from various sources to use our organized influence in assisting to promote legislation, to back some phase of the labor problem, or to lend our support to this or that project entirely outside of the scope of our Association. When it is clearly indicated that the project is entirely outside of our field of activity as set down by our organizers, it is an easy matter to refuse on the basis of such

grounds, but often the projects presented are on what might be termed the border line. On several occasions during my administration, and no doubt previously, such border line projects have been presented. In order to clearly define the legitimate field of the A. F. A., I sometime ago proposed to Secretary Hoyt that at the meeting of the Board of Directors held during this Convention, the subject be presented for discussion and legislation. The question being, should the A. F. A. confine its activities to the truly technical, as many of our members believe, or should we cover all subjects of whatever nature which are of interest and benefit to the casting industry as a whole, or had we best, as in the past, adhere strictly to the field as set down by our organizers?

Board Action

At the meeting of the Board held on Sunday evening last, the President was authorized to appoint a sub-committee on policy, that committee to report with definite recommendations at the November meeting.

Co-operative Research

Although our organizers had an understanding of the needs for research, I am sure they did not comprehend the advantages to be derived from organized co-operative research as we know it today. They had no thoughts of carrying on research except to the very limited extent possible through members of the Association giving to the industry through the proceedings of the Association the benefit of their researches. The dues of the Association as then proposed and as now existing, do not provide for such activity.

In Great Britain they have two distinct organizations, the Institute of British Foundrymen, an association that restricts its activities to technical papers and discussions, and the British Cast Iron Research Association, organized for research work only and independently supported by the grey iron industry. In France there was recently organized a malleable iron research association. In Germany the German Foundrymen's Association does excellent research work through its committees, presumably in the same manner as research is carried on in our

own Association. The present-day research associations have developed largely as a result of co-operation between the many units of an industry and the government bodies during the war period. During the war great expansion in productive capacity took place. After the war, with the war demand cut off, it became necessary to find new uses for some of our raw materials. This condition has led to the formation of such associations as the Copper & Brass Research Associations, the Zinc Institute, the Cast Iron Pipe Association, etc. These associations, supported by industry, have sought not only new uses for their products, but are endeavoring to improve the quality of the same and to render service of a technical and commercial nature for the purpose of reducing costs, creating more economical marketing conditions, etc. The American Malleable Castings Association, under the direction of Professor Touceda, has conducted research work leading to results of most outstanding character. Through the intensive research work of that association, malleable iron of undreamed of quality is now being regularly produced in a large commercial way. A steel founders' association is also in existence and has done good work in the improvement of the quality of steel castings. In the industry which this Association represents, in so far as I am aware, the first organized effort in the direction of true co-operative industrial research was taken by a small group of electric steel founders having plants in non-competitive locations, by having organized the Electric Steel Founders' Research Group. Our Past President, Major R. A. Bull, is Director of Research of that association. That group, with the combined financial support of its members, conducts research work in a truly organized manner. The objects of this co-operative research group is to improve the quality of its product and reduce costs. The experience and knowledge of each is used for the benefit of all.

Great possibilities in the way of research carried on by joint committees, has been most forcefully manifested by the work of the Joint Molding Sand Research Committee, organized by the National Research Council, but actually fathered, financed, and conducted by the A. F. A. This committee consists of 48 men, appointed from several technical societies and

government bureaus. Its work has been carried on through the liberality of A. F. A. members who have contributed substantial sums for the work. Since the last Convention the Sand Producers' Association has become officially represented on the joint committee. The results of the committee's work to date are embodied in a pamphlet recently issued. These results have been presented and discussed at this convention and form a valuable contribution to the literature on the subject. The committee has presented practical methods for testing molding sands with relatively simple and inexpensive equipment. Tests are easily conducted by untrained men after acquiring a little experience. The committee has also reported on many samples of sand secured through the geologists of several states and from other sources. Other work being undertaken by the committee is that of conservation and reclamation of molding sand.

International Research

The first research work of an international character was given its impetus arising out of a resolution adopted at the International Meeting of Foundrymen, held in Paris in September of last year. This resolution is as follows:

RESOLVED: That the International Congress of Foundrymen, assembled in Paris, recommends that the testing of cast iron be differentiated in the testing of quality of the iron entering the castings from the testing of the quality of the castings themselves.

That immediate steps be taken to study both subjects side by side in the expectation that the first subject will be solved earlier than the second.

That it is recognized that in no case will the testing of the quality of the iron give reliable information as to the testing of the quality of the castings made with it.

That a joint committee be appointed from the countries here represented to make suitable recommendations carrying this proposal into effect.

The work as suggested in this resolution in this country was given in charge of our Committee on Grey Iron Castings,

of which Mr. Harry Swan is Chairman. The program of study to be followed to determine the American recommendation of an arbitration test bar is to include.

(a) A study of the relations of different sizes and shapes of test bars to be used to determine the quality of the iron in the ladle.

(b) A study of the relation of the test bar to the casting.

The purchase of a Portevin-Fremont machine was authorized by our Board. By means of this machine it is possible to make the physical determinations on a test bar taken from a casting with a hollow drill. This machine is now in this country and the work is under way.

Work of Committees

The work of the Joint Molding Sand Research Committee and the Committee on Grey Iron Castings has been briefly referred to above. I will now briefly outline the work of our various committees during my administration:

Due to the decision of the Board to revert from the practice of the past few years of holding Spring Conventions to conventions held in the Fall, my term of office will span a period of almost two years. Because of this fact there have been greater accomplishments than otherwise would have been possible in the short space of one year.

The Committee on Industrial Education and Training of Apprentices, Dean C. B. Connelley, Chairman, has organized for the present Convention what I believe is the most important, most comprehensive and the most practical presentation of the subject that has ever been attempted. That committee has also organized and sponsored an exhibition of the work as now so practically carried out in the plant of the Falk Company of this city.

Our Committee on International Relations, with Mr. H. Cole Estep, Chairman, arranged, through co-operation with the representatives of the English, French and Belgium Associations, for a most successful tour abroad of the delegates of our Association last Summer. Mr. Estep, in his paper to be today presented, reviews the work of his committee and the advantages

accruing because of the closer contact between the foundry associations of the world. Our American party, numbering 45, including ladies, joined with the delegates of the British Institute of Foundrymen and their ladies in London and went in a body to Paris to attend the first International Foundrymen's Congress, sponsored by the Association Technique de Fonderie and held in the city of Paris in the middle of September of last year. Many creditable papers were presented. Papers were presented in both the French and English languages. An exhibition of foundry supplies and equipment was held in conjunction with the Convention and was quite creditable indeed. The exhibition gave our members an excellent opportunity for studying foreign foundry methods and equipment. An excellent program of entertainment and sight seeing was provided. Eight nations were represented at the Congress. The banquet held upon that occasion at the Hotel Palais d'Orsay was a wonderful affair. Music was supplied upon that occasion by a military band of 52 pieces and was naturally quite inspiring. We were later entertained by the French Association in the city of Nancy. An impressive reception was tendered by the Mayor of Nancy at the City Hall. It was in that building that the French Foundrymen's Association was organized in 1912. We were later entertained by the Belgium Association in the form of a banquet in the city of Liege and sight seeing tours, including some of the large industrial establishments of their city and one of the forts of the city which so bravely resisted the first German onslaught in 1914. We were personally conducted through the fort by Commander Naesson, who commanded the fort upon that occasion.

Those of us who were fortunate enough to be members of the European party, and to have enjoyed the genuine hospitality extended to us and the opportunity afforded for broadening our views and for studying foreign plants, methods and practice, owe a great debt of gratitude to the members of those foreign associations whose hospitality we so much enjoyed. Our Board of Directors has forwarded illuminated resolutions, so happily and beautifully worded by Past President Howell, to the several foreign associations and the branches thereof who were so kind to us upon the occasion of our tour.

In recognition of the able work of Mr. Estep as European representative and Chairman of our Committee on International Relations, our Board adopted a suitable resolution commending him for his excellent work.

The Board of Awards, with Mr. C. R. Messinger, our immediate Past President as Chairman, has completed all the preliminary work in connection with the permanent establishment of the A. F. A. awards, five in number, made possible through the most generous endowment of the donors, whose names will be indelibly recorded just so long as the A. F. A. shall remain in existence. Mr. John A. Penton, Mr. J. H. Whiting, Mr. Wm. H. McFadden and Mr. Joseph S. Seaman, in the establishment of the medals of award bearing their names, will forever inspire and lend encouragement to the foundryman. The S. Obermayer Award, which was established and in working prior to my administration, has each year since its establishment served the very practical purpose which its donor had in mind. For the first time, this year the John A. Penton Award will be made to one of our distinguished members, Professor Enrique Touceda, for his leading and outstanding work in connection with improving the quality of malleable iron, and the J. H. Whiting Medal, will be presented to Mr. John Howe Hall for his distinguished work in connection with the manufacture of steel castings.

The Committee on Foundry Costs, under the able guidance of Mr. W. B. Greenlee, Chairman, has formulated a comprehensive statement of the essential elements that should be embodied in a practical and satisfactory method for establishing foundry costs. This committee has also been responsible for a number of educational articles appearing in our Bulletin on the subject of Costs.

The Committee on Standard Pattern Practice has been reorganized under the able chairmanship of Mr. E. S. Carman. This committee is a joint committee, having representatives from seven national societies. Recently the American Society of Mechanical Engineers has requested representation on the committee. This request of course will be gladly granted. The committee has been assisted in a substantial way by the action

of the Board in authorizing the services of a paid secretary, Mr. Haughton. The work of this committee is being very intelligently directed, and will, I am sure, result to the greater advantage, not only to the foundryman, but to the consumer of castings. The committee's work will do much to reduce one cause for industrial waste, and thereby reducing to that extent the tremendous amount recently referred to by Secretary Hoover.

The Committee on Convention and Exhibits, with Past President Messinger as chairman, has done most excellent work in arranging for the record breaking exhibit now being held in this city of Milwaukee. To that committee belongs most of the credit for the success of the 1924 Exhibition.

The Committee on Papers and Publications, with Mr. E. F. Cone, Chairman, and Mr. R. E. Kennedy, Secretary, has developed a program of high technical merit, a program well rounded out with papers of decided interest in connection with apprenticeship training and other subjects of direct interest to every foundryman. Papers arranged for the joint sessions of the Institute of Metals Division of the American Institute of Mining & Metallurgical Engineers are of unusual interest.

Other committees have all been actively functioning, viz.: Grey Iron, Steel, Malleable and Non-Ferrous Castings, Coal and Coke, Heat Treatment of Ferrous Castings, Metallography and Refractories, but time will not permit of a report concerning all these activities.

Joint Committee Activities

Co-operation with the American Society for Testing Materials has continued in the most satisfactory and cordial manner. Following the action taken a few years ago, our Association is now, through its co-operation with the American Society for Testing Materials, depending on such joint activity for the adoption of standards for the materials of engineering of interest to the foundry industry.

Other joint committees on which the A. F. A. is represented are the Ferrous and Non-Ferrous Metals Committees advisory to the Bureau of Standards, and the Committee on Investiga-

tion of Phosphorus and Sulphur in Steel; Classification of Iron and Steel Scrap; American Engineering Standards Sub-Committee on standard sizes for brass crucibles, Corrosion Committee, etc.

Membership Campaign

Several plans for increasing the membership of our Association and thereby extending its usefulness to the industry were considered by the Board, with the result that Mr. Allan Ackley was engaged. His campaign through a carefully preconceived plan of approach and follow up, supplemented by direct efforts at this Convention, is showing gratifying results.

I wish to take this opportunity for extending to the officers of our Association, to the chairmen and members of our several committees, to the Foundry Equipment Manufacturers' Association and the Foundry Supply Association, to the local committee, and particularly Mr. Raymond Doty, who was responsible for the executive direction of all local committees, my sincere thanks for their most valuable assistance and co-operation in so ably and cheerfully assisting in the accomplishments to be recorded for the period during which I have had the honor and great pleasure of serving you in the capacity of your President.

A World Outlook for American Foundrymen

What the Growth of International Understanding Is Accomplishing

By H. Cole Estep,* Cleveland, Ohio

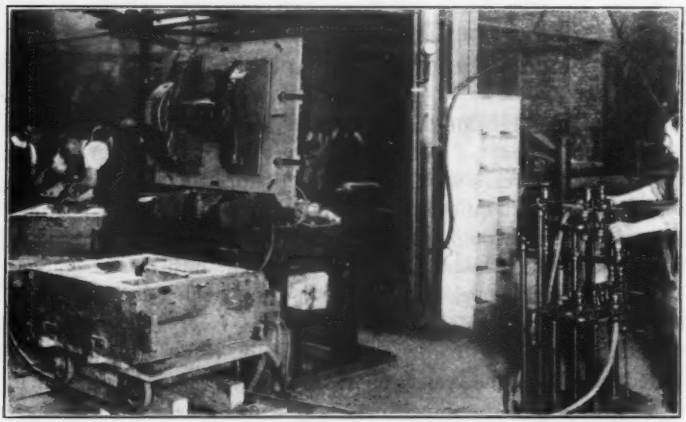
In the six years which have passed since the armistice there has been a great quickening of mutual interest among casting manufacturers throughout the world. Not only has the foundry industry of the United States been brought into closer contact with that of Europe, but European foundrymen have become much better acquainted with each other. Everywhere there is greater unity. This happy condition is the result of efforts initiated largely by the American Foundrymen's association, which have grown into the dimensions of a world movement that may easily have an important effect on the future course of industrial and even political history.

The significance of this great development in practical internationalism within the industry in which we are all so vitally interested is not yet fully manifested. We are in fact participating in a movement the whole power and sweep of which we as yet have difficulty in appreciating. Almost alone among the engineering trades, foundrymen in America now have the benefit of a world outlook and worldwide connections, which, as I shall endeavor to show, offer benefits of a very tangible kind. Without giving up any of our natural advantages or American characteristics we are in a position, as an industry, to make our influence felt abroad as it has never been felt before, and to absorb from the Old World much that would be beneficial to our own operations. This is what is meant by practical internationalism.

We have no desire to Americanize the foundry business of

*Chairman A. F. A. Committee on International Relations.

Europe, nor would we consent to any Europeanizing of the activities within our national frontiers. But the channels of communication which recently have been opened up between the American Foundrymen's association and the leading European foundrymen's organizations show that there is much to be gained



AMERICAN MOLDING MACHINES IN A PROMINENT BRITISH AUTOMOBILE CYLINDER FOUNDRY

on both sides by closer contact and knowledge of one another's methods and technical problems.

Beyond this it is beginning to be clear that in thus serving their own ends by getting together internationally, the foundrymen of the world are contributing in no small measure to the solution of a much larger problem—namely, to the cause of world peace itself. For peace comes of understanding and it is in the professional and business arenas that most international misunderstandings originate. Therefore the burden of promoting concord rests especially heavily on the shoulders of technical men and industrial leaders.

Foundry Industry Elevated

As Oliver Stubbs, twice president of the Institute of British Foundrymen, pointed out only a short time ago, at the New-

castle-on-Tyne convention, the political troubles of a postwar world will not be solved until business and professional men show a greater willingness to make their influence felt and to bring their specialized knowledge to bear. "Therefore," he said, "the value of these international contacts between foundrymen reaches far beyond the confines of our own industry. We are promoting the peace of the world by getting together." To which might be added that no set of men have done more since the war along this line than the producers of castings. The

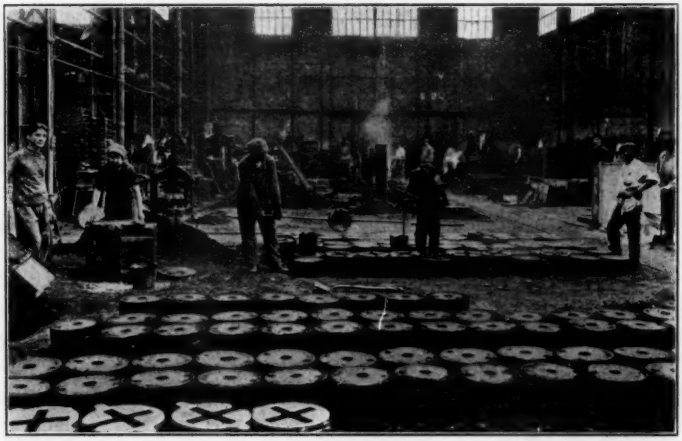
A BRITISH FOUNDRY EQUIPPED TO MAKE EXTRA HEAVY IRON CASTINGS

development of friendship in the past six years between the foundrymen of the world has been tremendous. All nations have contributed. One of the by-products of their efforts has been to lift the foundry industry everywhere to a plane of greater importance and dignity in the organization of human affairs.

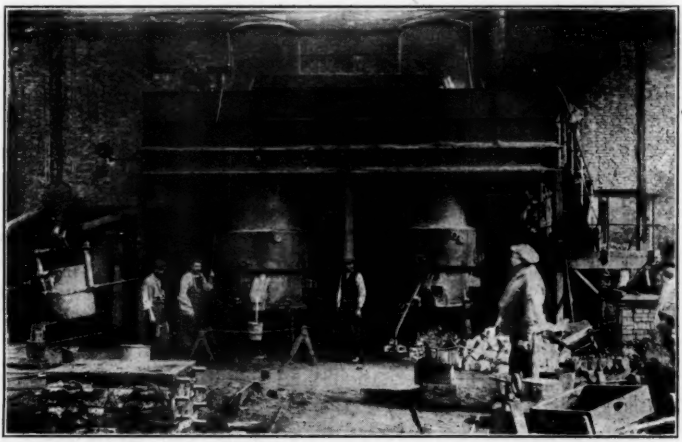
From this improved situation the casting manufacturers of

all countries are benefiting, indirectly and directly. The primary purpose of the American Foundrymen's association is to promote the interchange of technical information. The growth of the society and the position of influence to which it has attained is sufficient proof of the tangible value of the work it is doing. In the light of this, the usefulness of the 10 papers on practical foundry subjects which have been contributed to the proceedings of the American Foundrymen's association in the past three years by foreign authors can be judged. These papers were written by men who have the highest standing in their respective countries. To appreciate their importance it is necessary only to review the list of titles and authors presented herewith. These papers represent a volume of information on European foundry methods which greatly exceeds anything of the sort made available to American producers during the decade or two prior to the war. A point to be emphasized is that these valuable contributions to our foundry literature have been written expressly for American readers, which means that they contain far more than the usual number of suggestions which American foundrymen could utilize profitably in their daily work. In addition they are reinforced in most cases by a full discussion by leading American foundrymen, who have pointed out the exact way in which the suggestions offered can be applied to our own conditions.

All this is a result of the growth of international co-operation which has been outlined briefly in the foregoing, coupled with the specific arrangements for interchanging information with European foundrymen's associations which have been perfected by the American Foundrymen's association since 1920. Some further details of this exchange of papers arrangement will be given later on in this communication. At present it is sufficient to point out, as further evidence of the great strides made by the foundry industry recently, that in no other branch of the engineering trades has anything of the sort been attempted, so far as the author is aware. The foundrymen of America alone are possessed of a working arrangement whereby the best European thought on the technical problems of their business is brought to their doorsteps.



A FRENCH FOUNDRY EQUIPPED FOR LIGHT REPETITION WORK



MELTING DEPARTMENT OF A PROMINENT FRENCH FOUNDRY

European Exhibitions

There are at least two other directions in which foundrymen are reaping benefits from their improved international outlook. One is found in the spread of the foundry equipment exhibition idea to Europe. Since the war there have been four such displays abroad. The first one was in Belgium, Sept. 18 to Oct. 10, 1921, at which there were 80 exhibitors. This exhibition, which included, like its successors, considerable American machinery, was held in Liege and was so successful that it was continued for a week beyond the original closing date. In 1922 there was an international exhibition of foundry supplies and equipment in Birmingham, England, June 15-24, at which there were 120 exhibitors. Paris held the stage in 1923, when a display of 100 exhibits was held Sept. 2-16, in connection with the first postwar International Foundrymen's congress. This year there was another exhibition in England, which was held in Birmingham, June 19-28. These foreign exhibitions, although on a smaller scale than those held by the American Foundrymen's association, possess one feature of great practical value. There have been included in every case representative displays from five or six different countries on both sides of the Atlantic, thus affording the visitor a unique opportunity to study the development of foundry equipment and machinery comparatively. Those who have not been able to attend in person have had the benefit of extensive reports in the technical press. There have also been two or three such exhibitions in Germany since the war. There are no records of any comparable activities in the exhibition line in the 20 years from 1894 to 1914. These displays and the stimulus they have given to mechanical and technical advancement in the foundry field are a direct result of the improved relations between foundrymen which now exist throughout the world—and in the creation of these better relations American foundrymen have played no small part.

The growth of international co-operation has also stimulated closer personal ties between the foundrymen of the various European nations and between those of the Old World and the New. There has been a healthy increase in travel back and forth. The culmination was reached at the International Foun-

drymen's congress in Paris last year, which was attended by a large delegation of members of the American Foundrymen's association, and the representatives of 11 other nations.

Taken together all this activity is resulting in a quickening of the development of the foundry industry along both business and technical lines. Without surrendering any of their nation-

A LARGE FRENCH FOUNDRY EQUIPPED FOR HEAVY WORK

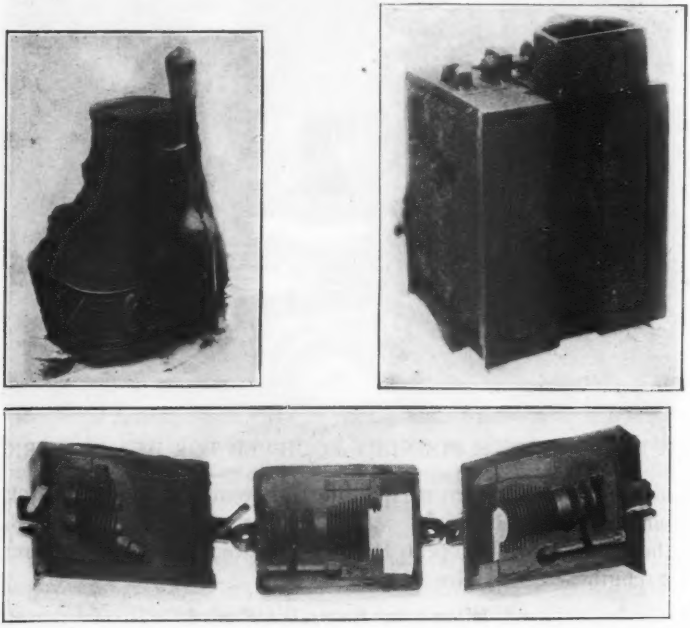
alism the foundrymen of the different countries are influencing one another in beneficial ways. As far as we are concerned, the influence of European foundry practice on America is being strengthened, and vice versa.

Where the Roots Lie Buried

In at least two directions European foundry practice has been of great service to America. It is to Europe that we are largely indebted for our craftsmanship. European foundrymen possess an all around training which it is difficult to obtain in the United States at present. Therefore it may be said that more than anything else they have brought us skill. This we

have adapted and improved to suit our own conditions, but the cradle of foundry business was in northwestern Europe. There were skilled molders in Europe when America was still a wilderness. Cannon balls and a large iron gun were cast in London in 1516. One of the earliest European foundrymen, in the commercial sense, was Dud Dudley, an Englishman who obtained a patent for the manufacture of iron castings from James I in 1619—a year before the founding of the Plymouth colony.

A little more of this history is interesting to show how the



BRITISH METHOD OF MOLDING AN AIR-COOLED CYLINDER

roots of the American foundry industry are buried deep in European, especially British, soil. Dud Dudley was one of the first writers in the world on foundry subjects, and his book, "Metallum Martis," mentions various castings which he made for mil-

itary and civilian purposes. Common iron castings, however, were not produced regularly in Europe until towards the eighteenth century. It was about 1709 that the ordinary sand mold was introduced into England as a result of the efforts of Abraham Darby, who with four partners established the Baptist Mills at Bristol. The workmen were Dutch brass founders who had learned the art of making brass castings in sand in Holland. Their first attempts with iron were failures, and considerable loss was incurred in unsuccessful experiments. Finally one night Abraham Darby, with the assistance of a young workman named John Thomas, succeeded in casting an iron pot. From that time forward iron founding grew and flourished in the British Isles, from which at an early date it was transferred to North America. At the same time there were parallel developments in France, Germany, and other continental countries, from the results of which early American foundrymen profited.

When one considers the obstacles which had to be overcome in those days, by rule of thumb methods without modern scientific aids, it can be appreciated why European foundrymen look with pride on the achievements of their forefathers. It also is evident that there is sane reasoning in their contention that methods and practices are not necessarily bad because they are old. There is virtue in the old as well as in the new. But what has resulted in Europe, which America has been fortunate in largely avoiding, is a peculiar combination of moss-grown traditions and modern ideas, the co-existence of antiquated processes and twentieth century methods. This is a product of the past and is only natural in countries which were old before the United States was discovered. It may have drawbacks, but it also means that the historically inclined European foundryman can draw inspiration from a past which fairly teems with great inventions in metallurgy and shop practice from which the whole world has benefited. But there is no reason why American foundrymen should not participate in this source of inspiration. This would enable us, along with the progressive manufacturers of castings in Europe, to create a practice in which is combined all that is best and tried in the old with those elements which are most promising and successful in the new.

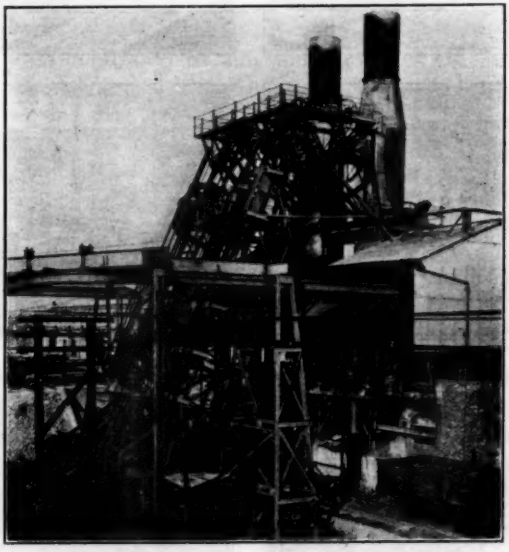
Modern Progress Abroad

Europe has not grown great merely by feeding on traditions. Her leading men, in any line of endeavor, have always been pushing ahead. Therefore in the modern theater, American foundry practice can profit by the closer contacts we are establishing with the Old World. Great as has been our advance in research work, there are directions in which we might profitably be influenced by the progress of Europe. Foreign foundry scientists are able to show us what can be done by individuals in the field of technical investigation. In both England and France there is a spirit of individualism in research work which is healthy. Take, for instance, Professor Turner's investigations of the effect of silicon, F. J. Cook's researches into the network phosphide-cementite eutectic in cast iron, or the Fremont-Portevin method of testing as tangible examples of valuable offerings which individual European foundrymen of scientific bent have tendered to their American confreres.

The contacts established in the past few years have given American foundrymen equal opportunities in the field of shop practice. Along this line the work of F. W. Stokes on centrifugal castings might be cited. This process opens up a whole new vista of casting manufacture. We have also the benefit of the study of foundry sands made by Prof. P. G. H. Boswell, while in the sphere of marine engineering, in which British foundrymen admittedly are leaders, the methods of molding large propellers, etc., developed by men like Wesley Lambert have been of great value to American producers. On the other side of the channel a distinguished French foundryman, E. V. Ronceray, has given us the benefit of his work on how to make castings without feeding heads and risers, a suggestion of great value to shops handling large quantities of metal, the cost of which runs into thousands of dollars a day. In short, the influence of European foundry practice on the American industry instead of being negligible comes nearer to being profound. At least the foregoing indicates how advisable it is for the progressive American foundryman to keep in touch with the latest European developments.

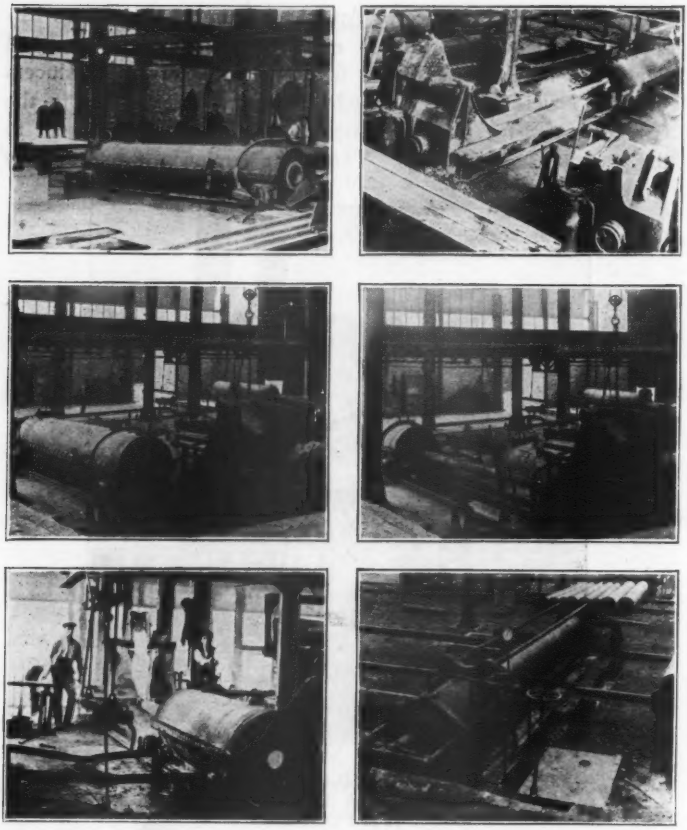
The reverse is equally true. Now that it is in the full tide

of manhood, the influence of American foundry practice on Europe is tremendous. This is creating new developments and tendencies in the Old World with which American producers would do well to keep in touch. Europe looks largely to the United States for the application of labor-saving equipment to the production of castings. There is a tendency abroad to pay



CUPOLAS WITH SKIP-HOIST CHARGING APPARATUS AT A LARGE ENGLISH PIPE FOUNDRY

attention to metallurgy rather than to shop practice, the latter being left more to the inherited skill of successive generations of molders. This means that the foreman in Europe occupies an exceedingly important position, left, as he is in many cases, more or less to work out his own methods. In the United States the shortage of skilled labor has forced us to develop ways of doing things by machinery, in the working out of which our large markets are a big help. So we are in a position to give leads to Europe in the direction of applying machinery and the



MANUFACTURE OF CAST-IRON PIPE BY CENTRIFUGAL PROCESS IN A LARGE ENGLISH FOUNDRY

(a) The Molding Machine.
(b) Machine Ready for Casting.
(c) Pipe Being Spun.
(d) Pipe Finishing Spin.
(e) Machine Showing Cantilever Pouring Through.
(f) Hydraulic Testing Apparatus.

energies of technically trained men to problems of shop practice. Our position in this branch of foundry work is more or less generally acknowledged. American molding machines are found throughout the length and breadth of Europe, while many of

the locally made machines show the influence of American design and inventive genius. Others, it is true, like the French hydraulic type, are decidedly original. In this category might be placed also the English electro-pneumatic machine. In general, however, America sets the pace. The same is more or less true of other kinds of foundry equipment.

American Methods Adopted

Naturally in the field of automotive castings the influence of American methods is felt abroad. On both sides of the ocean the specifications of automobile engineers have become constantly more exacting while the problems in the way of molding and coring which the foundryman is asked to solve are growing continuously more difficult and complicated. As a result, both in Europe and in this country, only those plants equipped and organized to turn out the highest grade of gray-iron castings have been able to make a continuous success of automobile work. To meet the requirements of this new industry specialty shops have been developed in Great Britain and on the Continent to produce motor-car and motor-cycle cylinder castings largely according to American methods, except that there is a tendency to adhere to dry-sand practice. The oil-sand core, on the other hand, has been almost universally adopted. The organization features and methods of up-to-date British automotive foundries such as those found in Smethwick and Coventry possess many features which had their origin in the United States. Near Paris there is now being built a new automobile factory which will be equipped throughout almost exclusively with American machinery and appliances, especially in the foundry. In Coventry, England, there is an exceedingly successful piston-ring foundry, the manager of which sticks closely to what may be termed the American idea of following out one definite line of manufacture to the point of exhausting its possibilities.

A recent issue of *The Foundry* contained an article describing how the introduction of a certain American type of molding machine is gradually transforming the practice and methods of one of the oldest and most famous foundry centers in Scotland. Bath tubs, which a skilled molder and helper turn out at a rate

of three or four per day, are being made with the help of this machine and a gang of three semi-skilled men and a boy at the rate of four or five per hour. In addition to such activities, we have the influence of the practice of American-owned plants in Europe, such as the foundries of the International Harvester Co. in Lille, France, or of the Ford Motor Co. at Cork, Ireland.

American manufacturing methods are influencing European foundry practice in another direction. The writer has reference to what may be termed the American conception of quantity production. That this is somewhat different from some European ideas of what they call mass production is evident from a superficial study of the situation. If in the next ten years America can give to Europe a true conception of what quantity production really stands for, it will be a contribution of the first magnitude to the material progress of the twentieth century. The idea that quality must go hand in hand with quantity production lies at the root of this problem. The idea persists in some European quarters, especially in the foundry field in England, that modern high speed production somehow implies a lowering of quality standards. It even is contended that these methods have all but eliminated the skilled workman and annihilated craftsmanship, without which a superior product cannot be produced. It is not always appreciated that what quantity production methods really imply is merely a change in the way in which craftsmanship is applied to the job. This aspect of the manufacturing problem seems to be grasped somewhat more readily on the Continent than in Great Britain, but a change of view is taking place on both sides of the channel. Gradually it is becoming evident that it is not necessary to follow slow, expensive, hand production methods to produce a quality product. Given raw materials of the proper sort coupled with methods that are right and an organization which insures the proper maintenance of standards, both as regards raw materials and process, and the result must be a satisfactory product of uniformly high quality. It is a question not of energizing but of controlling the processes of production. This is the view of America, which the writer ventures to predict will have a considerable influence on the

development of European manufacturing methods, especially in the foundry field, in the next 10 or 20 years.

From all of the foregoing it is evident that there is a great interchange of information now taking place in the engineering field between the eastern and western hemispheres. The Old World is influencing the technical development of the New and vice versa. Both sides are profiting, and there is more intercourse across the seas today than ever before. In the foundry business, therefore, the work of the American Foundrymen's association in foreign fields in conjunction with the Institute of British Foundrymen and the foundrymen's associations of Belgium, France, and other countries, is of the highest importance. Perhaps it can be ranked as one of the three or four most important things the association is doing, not only on account of its present value, but due to its future possibilities as well.

What A. F. A. Has Done

This work consists primarily in stimulating the interchange of information between the foundrymen of the world. In this direction the American Foundrymen's association has been a pioneer. In 1920 it entered into a formal agreement with the Institute of British Foundrymen to exchange papers dealing with important questions of foundry practice each year. The underlying idea of this arrangement is that every year the Institute of British Foundrymen will appoint one of its members to write a paper for the A. F. A. dealing with some phase of British foundry practice which would be of use to the industry in the United States. Likewise the A. F. A. commissions one of its members every year to send the British association a paper covering some feature of American foundry practice that might have European application. This agreement is now in its fourth year, and the results of its working have been so satisfactory that other exchanges of papers have taken place between the American and the French and Belgium Foundrymen's associations, and between the latter and the British association.

A great interchange of ideas has thus been set in motion, for the initiation of which the A. F. A. is responsible. A list of the papers exchanged so far is presented on another page. In com-

menting on this agreement in his annual report, W. R. Bean, president of the American Foundrymen's association, 1920-22, said:

"The American Foundrymen's Association recently has taken the lead among the technical societies of the country in establishing an intelligent exchange of technical information with similar foreign associations by making arrangements for an annual exchange of papers with the leading foundrymen's associations of Europe. Beginning with the formal agreement completed in 1920 * * * the arrangement has now been enlarged to include * * * the associations (respectively) of Belgium and France."

Abroad this suggestion of the American Foundrymen's association has met with a whole hearted response, and the best European foundry experts have been detailed to contribute to the A. F. A. programs. Commenting on the arrangements, the council of the Institute of British Foundrymen stated in 1922:

"We attach very much importance to the interchange of papers, and hope in the future much more progress will be made in this direction."

Accompanying this exchange of papers, and to some extent antedating it, there has been a series of visits which has contributed to the close co-operation that now prevails between European and American foundrymen. In 1919 A. O. Backert, at that time president of the A. F. A., paid an official visit to England and paved the way for much that has taken place since that time. In 1922 Oliver Stubbs, president, and Tom Firth, past president, of the Institute of British Foundrymen visited the United States. They were followed in 1923 by Emile Ramas, who came as president of the Association Technique de Fonderie de France. There have been numerous other visitors since the war on both sides. All this has contributed to the establishment of personal contacts of a more lasting and intimate character than have ever before existed between European and American foundrymen.

Last year a party of about 40 members of the American Foundrymen's association went to Europe in a body and travelled through Great Britain, France, and Belgium, where they were officially entertained. It is doubtful if any other body of American engineers or professional men ever received such courtesies from their confreres in so many different European countries. This trip was an object lesson in understanding between nations

along industrial lines, and in the importance of international contacts between representative business men. It culminated, as previously mentioned, in the International Foundrymen's congress in Paris, which was organized by the French association, and in which the representatives of an even dozen countries participated. At the opening session the platform was occupied by the heads of the foundrymen's organizations of six great countries, France, Belgium, Czecho-Slovakia, Italy, Great Britain, and the United States. The general secretaries of four foundrymen's associations, the British, French, Belgium, and American, also were present. It is doubtful if there has ever been a more representative world gathering of men engaged in engineering work. As a result of this congress an important international committee has been set up to try and work out a generally acceptable method of testing cast iron. The Paris convention was indeed a great occasion in the evolution of the foundry industry, and a foretaste of what may be expected from the second International congress which it is hoped to hold in this country in 1926.

Let Us Aim High

In concluding this paper, in which an effort has been made to sketch briefly the growth of international understanding among foundrymen and to indicate what it means to the industry at home and abroad, the writer feels he should return to the sentiments expressed by Oliver Stubbs, quoted above, as expressing the larger aims that should underlie any international movement among business and professional men. As Mr. Stubbs points out, what we are really working for is the peace of the world. If this be idealism, let it stand. Surely there can be no less worthy object. We learned from the last war, if anything, that industry loses more than it can ever gain from a conflict in arms. So even on their lowest terms, the efforts which American and European foundrymen are making to understand each other, and to promote peace, concord and technical advancement, are fully justified, while taken at their highest, they represent a real contribution to human progress.

PAPERS EXCHANGED WITH EUROPEAN ASSOCIATIONS

Papers Contributed by Institute of British Foundrymen to American Foundrymen's Association

1922—American versus British Cast Iron, by F. J. Cook, Past President, I. B. F.
1923—British Foundry Practice, by Percy Longmuir, Past Director, British Cast Iron Research Association.
1924—British Bell Founding Methods, by Wesley Lambert, Member of Council, I. B. F., and George Hall.

Papers Contributed by French Foundrymen's Association to A. F. A.

1922—Destruction and Reconstruction of French Foundries, a Memoir submitted by the Association Technique de Fonderie de France.
1922—European versus American Molding Machines, by E. V. Ronceray, Treasurer, A. T. F.
1922—A New French Electric Furnace, by R. Sylvany.
1922—A European View of the Malleable Problem, by T. Levoz.
1923—Aluminum and Light Alloys, by M. de Fleury.
1923—Address by Emil Ramas, President, A. T. F.

Paper Contributed by Belgian Foundrymen's Association to A. F. A.

1922—Making Typewriter Frames in a Belgian Foundry, by Joseph Leonard, Past President, A. T. F. de Belgique.

Papers Contributed by American Foundrymen's Association to Institute of British Foundrymen

1921—The Basic Hearth Electrical Furnace and Some Problems of Cast Iron, by George K. Elliott, Cincinnati.
1922—American Methods of Manufacturing Malleable Iron Castings, by Prof. Enrique Touceda, consultant, American Malleable Castings Association.
1923—American Methods of Producing Steel Castings, by R. A. Bull, Past President, A. F. A.
1924—The Production of Castings in Permanent Molds, by Robert J. Anderson, U. S. Bureau of Mines, and Edward M. Boyd.

Papers Contributed by American Foundrymen's Association to French Foundrymen's Association

1922—Malleable Iron Castings, by Prof. A. E. White and H. E. Gladhill
1923—The Bonding Substance of Molding Sands, by H. B. Hanley Rochester, N. Y.
1923—Testing Cast Iron, by Dr. Richard Moldenke.

Report of the Committee on Foundry Costs

To the Members of the American Foundrymen's Association:

No report was made by this committee last year, so that what is said here will cover that year as well.

Before taking up the problems which have confronted this committee, it may be well to explain just what has been done by the cost committee of this association in the past in the matter of cost finding methods.

In the year 1919 an arrangement was made by the directors whereby a cost system, devised by a firm of accountants for some of our members, could be installed by that company in the plants of other members at an agreed price, and this system was printed in the *Transactions* for that year. It was somewhat elaborate and went into considerable detail in the analysis of accounts so that it did not seem to be well adapted to the average foundry.

In 1922 the committee endeavored to devise a simpler system* which could be expanded for the use of the larger firms or contracted for the smaller ones. This system has not been generally adopted, but was a step in the right direction.

This was the situation when the present committee came into office two years ago.

Our first task was to analyze the situation carefully to determine just how the Association could properly help the members. We found that our membership was composed of many types of foundries making grey and malleable iron, steel and non-ferrous castings, and that conditions varied greatly in the different classes so that it would be impossible to devise a cost system which would apply to all. We then said, "Let's start at the bottom and find out what is common to all," and we decided on a number of fundamental principles which we felt applied to our industry as a whole. These have been carefully considered

**Transactions*, American Foundrymen's Association, vol. 30, pp. 282-304, 1923.

and have been recommended for the use of the members by the Board of Directors. They are as follows:

1. Costs should be determined for pounds of good castings produced during stated periods (usually monthly) for individual castings, classes, customers, or the foundry as a whole as conditions may require.
2. Cost factors should be distributed departmentally so far as practicable.
3. In figuring costs of individual castings, classes or customers, certain expenses should be applied specifically. The expenses which cannot be charged directly should be applied partly on the basis of direct labor and partly on the basis of a uniform cost per pound of good castings produced.
4. Costs should be kept according to the way sales quotations are made, that is, either by individual castings, classes or customers. This will make it possible to compare Costs with Selling prices.
5. Costs should include all expenses incident to the manufacture of castings including interest, depreciation and reserves.
6. Cost estimates prepared for the purpose of determining sales quotations should be based upon normal operation and current market prices. Normal operation means that percentage of full operation, which will represent average business taking into account class of work and facilities. This percentage will be somewhere between minimum and maximum and should never be considered the maximum. The purpose of figuring normal costs at all times is to absorb during periods of good business the idle expense incurred during periods of low production.
7. In making cost estimates for the purpose of sales quotations consideration should be given to the yield or the percentage of good production to the metal charged. It is believed the importance of yield as a cost factor is not generally recognized by the foundry industry.

Your committee has realized the need for better methods of cost finding among a large percentage of the members of the Association and have held a number of meetings to discuss means for assisting them.

Standardization of cost finding methods by associations is successful when the members are engaged in similar lines of work, when the members come in contact with each other in a competitive way, and when the problems are nearly the same.

In nearly all associations where uniform cost systems are successful, a competent man is employed to devise and install such a system and to see that it is kept up by the members.

One of the first recommendations which our committee made to your directors, therefore, was that the scope of the activities of the association be enlarged to permit the employ-

ment of a practical foundry cost man to devote his entire time, with such assistance as might be necessary, to aiding foundrymen to install systems suitable to their needs and to be of assistance to them generally in the cost finding problems. It was felt, however, that the finances of the association would not warrant an outlay for a department of this nature at the present time, and that the committee should confine its activities to doing what it could to urge upon members and local foundrymen's associations, the necessity for better cost finding methods and should solicit papers from members along these lines.

The activities of our association in the past have been devoted largely to the mechanical operation of the foundry since this is the phase of the business which appeals to many, perhaps most of our members.

Cost finding in the foundry and the application of the results attained for making prices, for control of operations and for the saving of waste should be of equal importance to foundry owners.

It is hoped that during the coming year increased interest may be shown by the members in both cost and management problems in the foundry so that these subjects may be given the prominence they deserve in the work of our association.

W. B. GREENLEE, *Chairman*

Departmental Costs in the Foundry

By Howell B. May, Shreveport, La.

The purpose of departmental foundry costs is to provide detailed information as to the separate components of cost which have entered into a product. General accounting shows the total profit or loss of the business as a whole; engineering or departmental costs show the profit or loss on each unit, whether the unit be the job, contract, line of product or operating department.

With departmental costs profitable and non-profitable lines are clearly recognized, thus enabling the sales department to choose the line for their greatest effort; non-profitable lines, it is true, are not always abandoned. They may be continued:

1—For their advertising value;
2—For the purpose of completing a line;
3—For the accommodation of substantial customers of the profitable lines; and
4—For maintaining production in slack seasons due to the fact that part of the overhead is fixed and continues regardless of the change in the volume of production.

If a non-profitable line is continued for these or any other reasons, it is of the greatest importance for the foundryman to know just how far he can maintain the policy.

Departmental costs aid all divisions of a business; sales, financial and operating departments.

The sales department in addition to knowing the profitable and non-profitable lines is enabled to fix selling prices and to plan sales campaigns intelligently through up to date information of current and unusual costs.

Cost Data More Important for Future Requirements Than Past History

The financial department should consider cost data more than history. This data through careful analysis may be used in estimating present and future capital requirements.

Detailed costs are not alone necessary for the establishment of selling prices, but are of far more importance as an aid to managerial control. They are of great assistance in the elimination of wastes of materials and labor. They also show whether or not operating capacities are being utilized efficiently.

The executive, through detailed records, is enabled to determine the departments where expenses are high; to determine the cause of such extra expense; and to take such steps as may be necessary to overcome or reduce same.

Detailed costs furnish a means for the careful study of operations, enabling the department foreman to make improvements and bring about reductions in the cost of operation. A lot of figures bunched into one total are of no use to an operating department even though they represent the correct cost of a product. To be of value the cost of each component part or process must be known; then and then only can a constructive analysis be made.

Properly organized costs not only give conclusions with reference to past performance but so present the elements of cost as to enable the executive to establish a control over the business from the anticipative standpoint.

Labor is made more efficient through the proper planning, scheduling and supervision afforded by production control, an essential requisite if costs are to produce the greatest returns. Cost control gives a dollar check upon the progress of these methods in intimate contact with the doing of the work.

Material likewise is subject to a similar control and this part of costs should indicate any unusual conditions, losses or wastes.

Overhead or burden is the most difficult problem in the establishment of cost control and, although by far the largest single item of cost, it is usually the least understood and the least controlled. If, however, it is handled from a logical stand-

point based on practical experience and a thorough analysis of operating conditions, burden can also be subject to a very accurate and immediate display of timely facts. It is really surprising how far burden or indirect costs can be controlled when accurate analysis is at hand and when a check upon those responsible therefor is kept.

Adequate cost control will furnish you with the following:

1—Timely and accurate knowledge of the work in process as to its cost, with a monthly analysis, thus preventing possible serious conditions from going unknown until too late to remedy same.
2—Timely and accurate knowledge of the cost of each contract or job as it progresses.
3—Monthly profit or loss statements and inventory balances.
4—Indications of leaks and dangers as well as good points of management and policies.
5—A basis for the establishment of equitable piece or bonus rates.
6—A basis for true, accurate and quick estimates on new work.
7—Display and running comparisons of actual burden and expense in each department.
8—Display of the value of inventory accounts, and monthly comparisons with work completed.

For the successful operation of any business it is necessary to provide for main and subsidiary departments. This same departmentalization is also indispensable to the successful application of foundry costs. In fact, organization, production control, management and foundry costs are so closely related that it is almost impossible to divorce them. The cost engineer must be familiar with the principles of management and good organization as well as the principles and practices of cost accounting, and, what is more important, he must know how to correlate or tie up the cost work with management.

The assignment of definite responsibility is absolutely necessary both from the point of view of management and the cost engineer. The definite assignment of physical and financial re-

sponsibility constitutes the essential conception of departmentalization. Coupled with the definite assignment of responsibility is the necessity of providing the means of reflecting the results of this responsibility in figures.

The character of each department influences in a large measure the selection of a suitable cost plan. Another important factor to consider is the nature of the operations for which each department head is responsible. It is often found necessary to have two different burdens in the same department, for example, machine and floor molding. The one has to carry power and maintenance charges which do not enter into the other.

In addition to the regular expense departments which must be absorbed in the producing departments, it is frequently necessary to provide for subsidiary departments or cost centers. For example, the process of heat treating may not warrant a physical department for that work alone; however, it must be treated as a cost department in order to properly collect and distribute the cost to the product.

Some of the fallacies of the average cost plan are burden and expense incorrectly distributed; producing and expense departments improperly segregated; burden and expense items inadequately analyzed; and costs not tied up and made an essential part of management.

As previously shown, organization, production control, management and cost work are so closely associated as to make it almost impossible to separate one from the other. The same analysis of departments as to responsibility and operations necessary for cost work can be used to formulate definite plans of organization. Exactly the same records required for adequate costs can be used to plan and schedule operations of machines, work places and departments. These same records may also be used for the establishment of equitable bonus rates.

Cost work, organization and production control can be carried on at the same time. The cost work may be made in conjunction with a revision of the general accounting system or entirely independent of same, but should at the proper time be tied in with the general accounting through a series of control ac-

counts which take the total figures at the end of each month or costing period and by means of the regular journal or voucher entries make them a part of the general accounting.

In order for a cost plan to be properly devised a careful analysis of each department must be made to determine the correct basis on which to distribute the burden and expense items; to determine the accounts necessary to supply adequate information and analysis; and to determine the proper organization for carrying on the work. The most essential point is to have the cost plan designed to fit the special needs of the plant.

Straight Tonnage

It is unfortunate that many foundries still use the straight tonnage or average flat cost per pound of all castings produced.

This plan is fundamentally unsound except where one product is made, or where all castings have practically the same weight, the same molding and core time, the same degree of intricacy, and the same percentage of loss. Foundrymen know, however, that these conditions are rarely found on dissimilar castings, consequently the average flat cost per pound is applicable in very few foundries.

The inadequacy of the flat cost per pound has been demonstrated many times not only for the purpose of establishing selling prices but for managerial control.

It is about as sensible for Henry Ford to average the cost of the Lincoln and Ford as for the foundryman to average his costs on dissimilar castings.

Since the average flat cost per pound is fundamentally unsound it will not be discussed further.

Source of Cost Data

In order that costs may be properly determined there are certain channels through which must flow a steady stream of information to the cost department.

A stock record should be kept of all raw materials and supplies. The cupola or furnace charge sheet serves as a requisition for pig iron, scrap and all materials used in melting. For all other supplies a requisition should be used which shows the

proper charge account and correct pricing of all material required.

A set of charge accounts is necessary for all major divisions of indirect expense in each department. These charge accounts must be in such detail and must be analyzed very carefully if the full managerial benefit is to be derived.

All materials and labor chargeable directly to a job should be accounted for on production orders which constitute the authority to do a given work, these entries being derived from time cards and requisitions. All labor, both direct and indirect, must be accounted for on time cards. An analysis of defective castings is an important record in connection with the managerial costs.

Forms are simply the vehicles to convey information. The chief requisite is that they must be adequate and comprehensive.

Divisions of Foundry Costs

The manufacture of castings involve a number of operations, each of which presents its own problem of cost treatment.

The melting of metal is distinct from the succeeding operations. The molding department has problems which are not found in other departments.

The nature of the operations determine the cost divisions into which the foundry should be divided.

The following cost divisions usually cover the average foundry:

1—Melting.
2—Molding burden and machine hour rates.
3—Core burden.
4—Annealing cost.
5—Cleaning and finishing cost.
6—Sand, pattern and flask cost.
7—General expenses.
8—Standard rates.

Melting Costs

In setting up the charge accounts for melting department a distinction must be clearly made as to where the melting department leaves off and where the molding department begins.

In some foundries the pouring gang is part of the molding organization. The maintenance of ladles usually falls under the melting department.

As a general rule the conversion cost will cease upon delivery of metal at the spout in grey iron and non-ferrous foundries, while in steel plants the conversion cost ends with the delivery of metal to the molds. In malleable plants the practice is the same as grey iron, although some malleable plants have developed a practice similar to the steel foundries.

Another important consideration in the melting department is to have the charge accounts for metals so separated that fluctuations in market prices will be reflected in the materials section. These items cannot be controlled by the melting department, consequently the conversion cost is the real gauge of this department.

Should long time contracts for castings be made, it is evident that fluctuations in the market prices will materially affect the prices charged for metal on these contracts if charges are made on basis of average cost of metal. However, if metal is purchased to cover the requirements of the contract at prices prevailing when contract was made, a separate stock record should be kept of this specially bought metal.

Should no metal be purchased for the long time contracts, and a sharp increase in market prices is brought about there is nothing else to do but take the loss, if found necessary to buy at the higher price.

It is still the practice in many foundries to calculate the conversion cost on the basis of good castings produced. No attention being paid to the fact that one casting will have several times its own weight in gates and risers and in addition will have a high defective of 50 per cent to 60 per cent, while another casting will weigh ten times as much as the gates and risers and will have a loss due to defective of less than 1 per cent. In order to secure accurate costs under these conditions it is necessary to base the conversion costs on the pounds of metal poured, charging all of the conversion cost to the castings in question.

The defective castings and recoverable gates and risers should be credited back to the job at scrap value only.

This crediting back is not so difficult as it may seem. The defective comes from the inspection reports—while sprue ratios may be established which will facilitate the crediting of gates and risers.

Molding Burden and Machine Rates

The molding department is concerned with individual patterns, consequently the direct labor hour is the unit upon which to base the distribution of burden.

In the final anaylsis it is time that is being sold, therefore, it is only logical that wherever possible time should be the unit upon which to distribute departmental burden.

Many foundries still use the amount of money paid for direct labor as the basis of distribution of burden.

The fallacy of this practice is apparent in the following examples: If a job can be done in one hour by a 40-cent man and it takes an 80-cent man the same time—we have placed double the burden on the 80-cent man. This is manifestly unfair, since he has not used any more power, heat and light, depreciated equipment to any greater extent, nor absorbed a bit more taxes, insurance and other fixed expense items than the 40-cent man.

In order to more closely allocate costs, especially on jobs requiring the use of molding machines, a machine hour rate should be established which includes:

1—Depreciation.
2—Maintenance.
3—Power.

Labor of operators should not be included in the machine rate.

All labor in connection with the job should take the regular departmental overhead or burden rate and charges made in addition for use of machines based on machine hour rates.

Core Burden

All indirect expense in connection with the making of cores should be charged to the core burden account and this distributed

to the job on the basis of direct labor hours. This includes sand, binders and core oven expense.

Where machines are used for making cores, a machine hour rate should be established as in the molding department.

Annealing Costs

The item of annealing cost only applies to steel and malleable foundries.

In the malleable foundry the annealing cost is very important because of the length of time required for the operation. Charge accounts should be set up which show the various elements entering into the costs, such as packing, charging furnaces, unloading, furnace men and other contributing operations. If both annealing pots and muffled furnaces be used the costs for each process should be segregated. The cost is then distributed on the pound basis.

Annealing in the steel foundry does not present a very difficult cost problem. Here it is merely a matter of loading the castings on a car or in a pit and removing them. However, the elements of cost should be known so that economies may be effected. The cost is distributed on the basis of pounds annealed.

Any other heat treating operations should be handled in the same manner as the annealing.

Cleaning and Finishing Costs

The time required for cutting off gates and risers and other grinding and cleaning operations in grey iron, malleable and non-ferrous foundries is usually so small that it is impracticable to charge the direct labor to the jobs.

In the steel foundry, however, a very much different condition is encountered.

Where it is practicable to do so the cleaning and finishing direct labor cost should be determined and the burden distributed on the basis of direct labor hours.

A plan which has been tested out thoroughly in a number of plants and found to give a very close approximation is to assemble the entire cost, both direct and indirect, of all cleaning and finishing operations and distribute this cost on the basis

of the combined molding and core direct labor hours. Cored castings require a greater amount of effort to clean than do solid castings. By using the combined molding and core direct labor hours the cleaning of the outside is in proportion to the labor required to make the mold while the cleaning of the inside is proportioned to the direct labor required to make the cores. This method is manifestly much better than the tonnage basis used by some foundries.

The tonnage basis is unfair because solid castings weigh more than cored castings of the same volume and consequently absorb a greater cleaning cost; although it can be readily seen that more cleaning is necessary on the cored castings.

Sand, Pattern and Flask Costs

In the smaller foundries sand, pattern maintenance and flask cost on standard jobs is absorbed into the regular molding burden.

Pattern and flask expenses are charged directly to special jobs in the jobbing foundry.

In the larger foundries, especially steel, where a great volume of sand is consumed and where mechanical equipment is required for conditioning and handling, it has been found necessary to keep a separate cost of same. As the sand used is in almost direct proportion to the tonnage of metal poured this, then, should be the basis for distribution of the sand cost.

In the specialty foundry the maintenance of patterns for each product is charged directly to the line.

Any flasks specially built for a job should be charged to that job. The cost of metal flasks interchangeable for use as standard equipment should be set up in a flask account and this cost distributed on a basis of good castings.

General Expenses

Local conditions govern entirely the selection of charge accounts to cover contributing departments. Whether the foundry is a separate unit or a part of a larger plant also affects the selection of charge accounts.

Care should be taken to group all of these expense departments so that proper managerial control can be exercised.

The payroll department, the cost department, and similar departments serve all divisions of the foundry, and the cost of same should be distributed into those divisions. The best basis for distributing their expenses is through the total labor hours, both direct and indirect, in each department.

If a power plant is maintained the cost of operation should be analyzed very closely. Power is charged to departments on the basis of consumption. Trucking expense is charged on basis of service to each department.

It is essential that a practical basis be determined for the distribution of expense items to the departmental burdens and finally to the cost of the product.

Standard Rates

The cost of any one month can hardly be accepted as a criterion of the efficiency of a department. One month the repairs may be unusually high occasioned by the relining of a cupola or the rebuilding of the open hearth or air furnace and by other extraordinary expenses which must be absorbed by the product.

Experience has shown that an average of not less than six months should be used. A year's average will reflect a much truer condition.

In order to utilize the average cost to facilitate the work, predetermined or standard rates are made use of. These rates are established after careful analysis of the costs in each department over a period sufficient to reflect a true or normal condition.

The actual rates are determined each month and are compared with the standard rates. At the end of the next six months' period, another adjustment in rates is made. Should a wage increase or decrease be made during the interval, an adjustment may be made to take care of same.

A small balance of under or over absorbed burden will be determined each month. This may be carried directly to the profit or loss account at the closing period.

Standard rates may be determined and used for following: Conversion cost; metal cost; molding burden; machine hour rates; core burden; annealing cost; cleaning and finishing cost; flask cost; sand cost; pattern cost.

Causes of Failures of Cost Systems

Good cost plans have failed due to the lack of authority to secure the co-operation within the organization during the installation period, and after installation, when the cost man has left, through opponents of the plan. Again they have failed because of meddlesome clerks and minor officials making changes from time to time without determining just what effect these changes may have on the cost plan as a whole or the relation to other departments. When some important link has been destroyed in a cost plan it loses its effectiveness.

The design and installation of a cost plan should be intrusted to a man who has a practical knowledge of organization, production control, management, shop operations, and material handling as well as a knowledge of the principles of cost accounting. He should be given the authority and place in the organization which will enable him to carry through to a successful conclusion the work undertaken. When once a routine has been established as standard practice, no change should be made in that routine without the consent of an executive whose duty would be to analyze what effect the change would bring about in other phases of the work.

A cost plan to be of the greatest value must be designed from the engineer's point of view rather than from the accountant's. There is no question of the value of the accountant where the general and financial books are concerned but he is not so much interested in detailed burden and expense statements as the manager and department superintendents, upon whom rests the responsibility for operating at a minimum expense. Furthermore, the average accountant does not have the years of practical shop experience which is so essential in making a correct analysis of operating conditions, a prime requisite in the design of a cost plan.

Cost Finding in a Foundry

By W. J. Corbett, Chicago, Illinois

I.—Introduction

The subject of cost finding is of paramount importance to foundrymen who are engaged in a highly competitive industry requiring an intimate knowledge of facts. To carry on a manufacturing business without knowing the manufacturing cost, is indicative of business incompetence to which many failures are attributed. No matter how limited the volume of his business may be, an adequate and usable knowledge of costs is essential, if the foundryman would know definitely the results of his operations and be enabled, because of this knowledge, to control future operations intelligently and have a guide to establish selling prices advantageous to himself and to the industry in general. Small foundries as well as large foundries have adopted cost-finding methods to aid them in controlling production and marketing policies.

Factors Justifying a Manufacturer in Operating a Foundry

The existence of a foundry is justified only by its ability to create a satisfactory return on the capital invested and employed in the business. In order to do this, it is of the utmost importance that those in control of the business know and analyze all the elements of cost incurred in producing castings. They must be able to give reasons why expected results are not obtained, and to determine the procedure necessary to remedy such conditions. The facts necessary for an analysis of the business cannot be obtained from a bookkeeping system alone. The latter may show whether or not the business is being operated profitably, but it will not uncover deficiencies in either the manufacture or the marketing of the castings. If castings are being produced at a high cost or are being sold at a loss to the foundry, the management should have knowledge of such conditions in order to correct them and also to inform the stockholders why expected dividends are not received.

When the operations of a foundry are not profitable, antagonism or lack of cooperation is apt to occur between the producing branch and the selling branch, because there is a natural inclination for one to place the blame on the other; and this is particularly true when no facts are available to determine definitely where the fault lies. A remedy for such conditions is the use of costs for a guide by both the operating and sales departments. The effect of this on the latter will be to convert the selling forces from order-takers into salesmen, and thereby eliminate demoralizing factors in the industry. The effect on the operating department will be the expenditure of greater effort in economical production. In other words, the knowledge and use of costs should promote harmony in the foundry organization and enable the operating and sales departments to work toward a common goal.

Uses of an Effective Cost System

The uses of an effective system of cost accounting in a foundry may be summarized thus:

1. To acertain the cost of making castings.
2. To measure the efficiency of labor.
3. To ascertain the consumption of materials and supplies.
4. To serve as a guide for correcting faulty operating methods.
5. To provide the stimulus of chronological comparative records.
6. To furnish data for intelligent merchandising.

A foundry cost system that properly serves the above purposes must be practicable in operation. The data required by executives must be so arranged that it may be transmitted to operating and sales executives in a systematic manner, permitting quick and accurate analysis.

Three Functions of a Cost System

From the above, it is manifest that cost accounting has three general functions to perform. It must provide data for the preparation of financial statements; it must serve the management in controlling operations; and it must be a means for pre-

venting a serious loss in meeting competition. It is the main purpose of this paper to deal with the last named function by comments on the desirability of uniform cost-finding methods in the industry, and by a description of a method of calculating costs of individual castings.

II.—Uniform Cost-Finding Methods

Uniform methods of cost finding in an industry are without question very beneficial in promoting stability, business economy, efficient management, and lower costs. Uniform cost finding implies the use of the same principles and should not be construed as the use of standardized cost figures for an industry.

There are two fundamental requirements for uniform cost finding; viz., the use of a standard classification of accounts and division of the business into departments, and the use of a uniform method of applying indirect and overhead expense to individual castings. The first requirement ensures the charging of all the elements of cost to the proper accounts or departments. The second requirement ensures the elimination of great differences in costs among various foundries, which are caused chiefly by the use of different methods of applying indirect and overhead expense to individual castings.

A uniform method of cost finding in an industry is especially advantageous for establishing marketing policies. Vast differences in the costs of making specific castings at various foundries are usually due more to the use of different methods of cost finding than to methods of production or other economic conditions. The only true and logical differences in costs that should occur are those caused by the local conditions at certain foundries which enable the production of castings at different costs from those at other foundries. Wide variations in costs due to the use of different cost-finding methods are apt to be detrimental to the entire industry, and therefore, they should be minimized by the use of a more uniform cost-accounting practice. There will always be differences in costs of making castings at various foundries, but these differences should be caused only by certain local conditions such as location of plant, management, shop practice, purchasing, etc.

Comparison of Results Obtained by Different Cost Methods

To demonstrate the vast differences that are the results of using different methods of determining the costs of individual castings, Table I has been prepared by using eight different methods of cost determination which are some that the author

FIG. 1—COST OF THREE CASTINGS BY EIGHT DIFFERENT METHODS.

found in use while investigating cost-finding methods in about eighty different steel foundries. The burden or overhead rates used in the calculation of the costs were obtained from exactly the same cost figures, and therefore, the differences in the costs of the castings are due entirely to the use of different methods

Table 1

Costs of Individual Castings By Using 8 Different Methods of Cost Finding

Casting.	Weight Per Casting.	Per Cent Yield.	Direct Labor Per Casting. Mold.	Core.	Clean.	Total Cost Per Pound, Using Different Cost-Finding Methods. 1	2	3	4	5	6	7	8	Average.
A	2	28	.05	.01	.06	39.5	19.3	28.1	37.7	27.8	33.3	33.4	35.2	31.8
B	4	44	.03	...	.04	13.8	14.5	12.9	13.4	14.5	8.4	14.1	13.5	13.1
C	5	47	.06	...	.08	19.5	15.6	16.3	19.5	17.2	14.9	18.6	18.2	17.5
D	6	45	.14	.02	.04	23.1	16.3	24.0	22.5	18.7	28.5	21.4	26.6	22.6
E	8	36	.06	.02	.07	15.3	14.6	14.3	14.0	15.6	13.8	16.1	14.6	14.8
F	10	60	.15	.06	.10	21.0	15.9	20.9	21.2	17.7	22.6	19.5	20.4	19.9
G	12	30	.25	.06	.14	26.7	16.5	24.0	24.9	21.6	29.2	24.5	27.5	24.4
H	18	57	.12	.10	.16	15.4	14.9	15.5	15.5	15.0	14.7	16.6	13.5	15.1
I	20	65	.18	.02	.12	12.2	14.9	14.0	13.1	13.3	12.3	13.2	13.3	13.3
J	25	55	.14	.02	.20	11.5	14.2	12.0	11.7	13.2	9.3	12.8	11.4	12.0
K	35	72	.30	.09	.22	12.9	14.5	14.7	13.9	13.6	13.2	13.6	13.2	13.7
L	40	64	.20	.08	.24	10.6	14.1	12.2	10.9	12.5	9.6	12.0	10.3	11.5
M	45	49	.20	.15	.30	11.9	14.2	12.7	11.7	13.5	10.9	13.8	11.0	12.5
N	55	63	.35	.05	.28	10.2	14.0	12.3	10.5	12.4	9.9	11.8	11.0	11.5
O	60	52	.18	...	.14	6.6	13.3	9.5	6.5	10.8	6.4	9.5	9.8	9.1
P	65	52	.35	.05	.25	9.3	13.8	11.5	9.2	12.2	9.3	11.3	10.2	10.8
Q	75	46	.45	.15	.40	11.5	14.1	12.7	11.1	13.3	11.3	13.0	13.3	12.5
R	80	59	.50	.20	.60	12.5	14.4	13.4	12.7	13.6	11.4	13.5	11.9	12.9
S	90	50	.35	.12	.32	9.8	13.6	10.9	8.5	11.9	8.5	11.0	10.3	10.6
T	100	40	.60	.34	.75	13.9	14.5	13.8	13.1	14.7	12.9	14.9	13.0	13.8
U	125	68	.50	.28	.30	8.0	13.6	11.4	8.4	9.5	8.8	10.2	10.0	10.0
V	135	60	.90	.15	.75	10.8	14.1	12.6	11.1	12.8	10.4	12.3	11.4	11.9
W	150	58	.75	.10	.55	8.6	13.8	11.2	8.8	11.7	8.6	10.8	9.6	10.4
X	160	50	.50	...	.20	6.2	13.2	9.4	6.0	10.7	6.6	9.3	8.8	8.8
Y	180	61	.60	...	.40	6.4	13.3	9.6	6.6	8.1	6.3	9.2	9.5	8.6
Z	200	42	1.00	.10	.42	8.5	14.0	10.9	8.3	12.1	9.2	11.1	11.0	10.6

of cost finding. An analysis of the figures in the table emphasizes the desirability of the use of the same principles of cost finding by the members of each branch of the foundry industry. It is observed from these data and from Figure 1, that none of the methods gives consistently high or low costs, but that one method will indicate higher costs in some cases, and lower in other cases. When it is realized that a difference in cost of one-quarter or one-half cent per pound may be a governing factor in procuring orders when the quality is not considered, and that much greater differences than these occur when different methods of cost finding are in use by competitors, the necessity for the use of uniform principles of cost finding is apparent.

The eight different methods of using the same cost figures for calculating the costs of the castings in Table I are given below. The letters designating the different methods have no connection with the order in which the results of their use are arranged in the table. The term "yield" as used in the following means the weight of good castings in percentage of the total weight of metal charged into the furnace.

Explanation of Table I

A. The cost of metal is variable with the yield. Forty per cent of the molding indirect expense, except supervision, is a certain percentage of the molding direct labor cost; and sixty per cent of it is a fixed rate per ton. The coremaking indirect expense, except supervision, is a certain percentage of the coremaking direct labor cost. The total cleaning cost, except supervision, depends on the casting. The total general overhead expense and the departmental supervision are a certain percentage of the molding direct labor cost, with a minimum rate per ton for these expenses. Annealing cost is a fixed rate per ton.

B. The cost of metal is variable with the yield. The molding indirect expense is a certain percentage of the molding direct labor cost. The coremaking indirect expense is a certain percentage of the coremaking direct labor cost. The cleaning indirect expense is a certain percentage of the cleaning direct labor cost. Annealing is a fixed rate per ton. One-third of the works general overhead expense is a certain percentage of the com-

bined molding, coremaking, and cleaning direct labor costs. Two-thirds of the works genèral overhead expense is a fixed rate per ton. Administrative and selling expense combined are considered as a certain percentage of the manufacturing cost, the latter being the total cost without including the administrative and selling expense.

C. The cost of metal is a fixed rate per ton for all castings regardless of their yields. The indirect expenses, cleaning direct labor cost, and overhead expenses are combined and taken as a certain percentage of the combined molding and coremaking direct labor costs.

D. The cost of metal is variable with the yield. The molding indirect expense is a certain percentage of the molding direct labor cost. The coremaking indirect expense is a certain percentage of the coremaking direct labor cost. The cleaning indirect expense is a certain percentage of the cleaning direct labor cost. Annealing is included in the cleaning indirect expense. The general overhead expense is a fixed rate per ton for all castings.

E. The cost of metal is a fixed rate per ton for all castings. The indirect expenses, annealing cost, and general overhead expenses are combined and taken as a certain percentage of the combined molding, coremaking, and cleaning direct labor costs.

F. The cost of metal is a fixed rate per ton for all castings. The general overhead expense is allocated to the metal, molding, coremaking, and cleaning departments, on the basis of the total labor cost in each of these departments. The molding, coremaking, and cleaning department burden rates, therefore, include some of the general overhead expense. The molding burden is a certain percentage of the molding direct labor cost. The coremaking burden is a certain percentage of the coremaking direct labor cost. All cleaning and annealing expense is a fixed rate per ton for all castings.

G. The cost of metal is a fixed rate per ton for all castings. All expense for indirect items and general overhead, is a fixed rate per ton for all castings.

H. The cost of metal is variable with the yield. The general overhead expense is allocated to the molding, coremaking,

and cleaning departments, on the basis of the direct labor cost in each of these departments. The molding, coremaking, and cleaning department burden rates, therefore, include some of the general overhead expense. The molding burden is a certain percentage of the molding direct labor cost. The coremaking burden is a certain percentage of the core direct labor cost. The cleaning burden which includes annealing is a certain percentage of the cleaning direct labor cost.

Advantages of Uniform Cost Systems Cited by U. S. Chamber of Commerce

Among the many advantages offered by uniform cost accounting in an industry, the following are cited by the Department of Manufacture of the Chamber of Commerce of the United States in its pamphlet entitled, "Uniform Cost Accounting in Trade Associations":

"1. Provides the 'one best way' known to the industry to figure costs (although cost accounting is a progressive science and provision should be made for keeping the uniform methods up-to-date) thereby eliminating expensive experimentation by the members of the industry individually and independently.

"2. Results in a better informed competition within the industry.

"3. Inspires confidence in the public that selling prices are established by producers who have full knowledge of the costs of the articles offered for sale.

"4. Tends to make the manufacturer, who otherwise would fail to see the advantages of good cost accounting, convinced of the desirability of adopting the methods which his competitors are successfully using.

"5. Reveals lines of individual products which have been marketed on an unprofitable basis.

"6. Provides in addition to the above specific reasons, all of the valuable features of good cost accounting generally, among which are the following:
   (a) Shows the danger line below which goods cannot be sold at a profit; thus serving as an insurer of profits.
   (b) Acts as a guide to the value, efficiency, and waste of workers, machines, methods, operations, and entire plants.
   (c) Provides a reliable guide and basis for estimating the cost of prospective business.
   (d) Furnishes current reports for comparing major cost items with standards which are predetermined, and thereby measures and increases operating efficiency."

III.—Cost Accounts for Monthly Cost Summaries

No attempt will be made here to outline a general cost accounting system for a foundry, but reference is merely made to it to show in a general way the main elements of foundry costs, because the job cost system to be described later depends on the general cost accounts for furnishing the necessary data.

It is desirable in securing cost data that the divisions of the foundry be clearly defined, and that the direct and indirect expenses, and burden or overhead expense be collected under certain headings. These general divisions consist of the following:

1. The melting department, which controls all labor, including handling and preparation of scrap, furnace maintenance and repairs, connected with the furnaces and ladles; and the consumption of all materials and supplies used in conjunction therewith. Its province commences with the melting stock and fuel at the storage point and ends at the point where the steel is poured from the ladles. The chemical laboratory can be regarded as an adjunct of this department, in which case its cost of operation is charged to the latter.
2. The molding department, which controls all the labor of molding, the maintenance of equipment, and the consumption of all materials and supplies used in conjunction therewith. Its province commences with the materials entering into molding sand mixtures at their point of storage, and ends with the delivery of the castings to the cleaning department.
3. The coremaking department, which controls all the labor of coremaking, the maintenance of equipment, and the consumption of all materials and supplies used in conjunction therewith. Its province commences with the materials entering into core sand mixtures at their point of storage and ends with the delivery of the finished cores to the molding department.
4. The cleaning and finishing department, which controls all the labor of cleaning and finishing castings, the maintenance of equipment, and the consumption of all materials and supplies used in conjunction therewith. Its province commences with the receipt of the castings from the pouring floor, and ends with the delivery of them to the shipping department. It is here considered as excluding all heat-treating operations.
5. The heat-treating department, which controls all the labor in connection with the annealing, normalizing, and other methods of heat-treating castings, the maintenance of equipment, and the consumption of all materials and supplies used in conjunction therewith.
6. The general overhead expense, which includes all the expenses not enumerated in the above departments. Such expenses are: power, light, and heat; general repairs not chargeable to the departments listed above; yard department expense; shipping; engineering;

storekeeping; purchasing; production or order department; accounting department; inspection department; safety and welfare department; pattern department; insurance; depreciation; taxes; loss on defective castings after shipment; general office expense; advertising; selling expense; loss on bad debts; management salaries; officers' salaries; traveling expenses; freight not charged to material accounts; interest and rent, when it is the policy of the company to charge these to costs; etc.

In the above divisions of the foundry for cost purposes, the maintenance of equipment in each department is regarded as being chargeable to the department using the equipment. When it is the practice to charge the cost of all repairs and maintenance to a single account instead of charging it to the different departmental expense accounts, it would be regarded as an item of general overhead expense.

Classification of Cost Accounts

The following classification of cost accounts, based on the main divisions outlined above, can be expanded or condensed to suit the desires of those who are to make use of the data. It is essential that all elements of cost be included in the total cost.

Melting Department:
- *Metals:*
  - Pig Iron
  - Purchased Scrap
  - Own Scrap
  - Ferromanganese
  - Ferrosilicon
  - Other Alloys
  - Miscellaneous
- *Conversion:*
  - Labor
  - Fuel
  - Power for electric furnaces
  - Other power that can be definitely ascertained
  - Supplies
  - Repairs
  - Electrodes

Molding Department:
- *Direct Labor*
- *Indirect Expense:*
  - Indirect Labor
  - Supervision
  - Sand
  - Supplies
  - Flask and pattern
  - Repairs
  - Fuel for drying

Core Department:
- *Direct Labor*
- *Indirect Expense:*
  - Indirect Labor
  - Supervision
  - Sand
  - Supplies
  - Fuel
  - Repairs

Cleaning and Finishing Department:
- *Blasting:*
  - Labor
  - Material
- *Chipping*
- *Grinding:*
  - Labor
  - Material
- *Removing Heads and Gates:*
  - Labor
  - Material
- *Tumbling*
- *Welding:*
  - Labor
  - Material
- *Crane and Transportation*
- *Straightening*
- *Supervision*
- *Repairs*

Heat-Treating Department:
- *Labor*
- *Fuel*
- *Supplies*
- *Repairs*

General Overhead Expense:
- The accounts to be included here are given in item 6 above.

Total Cost:
- Sum of the above.

It is not recommended that the general overhead expense be prorated among the departments in the steel foundry because there is no satisfactory method for doing it on any other than an arbitrary basis. Besides adding complications to the cost system, the arbitrary allocation of overhead expense to various departments adds nothing to the effective use of costs in controlling foundry operations. There may be some justification for doing this in a machine shop where operating conditions differ from those in a foundry. It is important to plan the cost system to accommodate the foundry, and to make it as simple as possible without sacrificing accuracy. The first steel foundry cost system adopted twenty years ago or more was patterned

after machine shop cost systems in that the expense considered in this paper as general overhead, or part of it, was allocated to the various departments. This was found unsatisfactory in practice and discarded years ago by steel foundrymen who have apparently shown no disposition to return to the old methods of steel foundry cost accounting, which were found to be impracticable although they may seem to be correct from a theoretical viewpoint.

Cost summaries itemized to whatever extent desired by foundry executives, and including all the expenses for conduct-

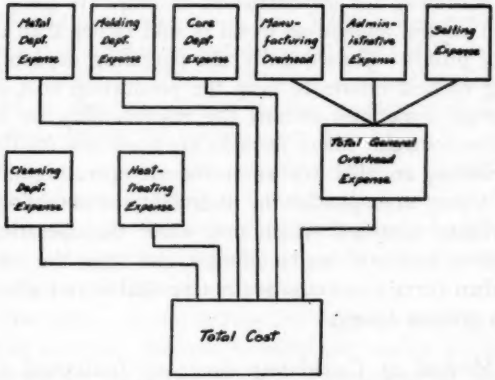


FIG. 2—ELEMENTS OF FOUNDRY COSTS.

ing the business, should be compiled monthly or semi-monthly. They are extremely useful for controlling operations as well as for furnishing the basic data required for calculating the costs of individual castings. The latter phase will be dealt with in what follows, as it is not the purpose of this paper to simulate previous publications dealing with accounting technique.

IV.—Cost of Individual Castings

It is conceded by many foundrymen that the subject of cost finding is perhaps the most important of any to be given thorough consideration in the future. Knowledge of monthly costs

of doing business is not enough, and further analysis of the business must be made by studying the costs of making castings from specific patterns. Without the information obtained from job costs, the foundryman has no guide to help him in reducing the cost of making certain castings or in eliminating from his business those jobs that he cannot make profitably.

The operating department of a foundry is sometimes unjustly blamed when expected profits are not obtained. The sales department may have taken some large orders by using weight schedules or some equally unsound method of securing them, instead of by using production costs as a guide. When such weight schedules for miscellaneous castings are used by order-takers, a certain amount of metal is sold rather than the expectation of profits. Consequently, the operating department, after exerting earnest efforts to keep the production cost at a minimum, must sometimes assume the responsibility for conditions beyond its control. These remarks are made not for the purpose of furnishing an alibi for an inefficient operating department, but for trying to emphasize the desirability of obtaining the costs of individual castings, which may show the operating department where economy can be effected, and show the sales department when certain castings are not profitable and what must be done to prevent losses.

V.—Method of Calculating Costs of Individual Castings

Different methods for calculating the costs of specific castings have been advocated from time to time, and consequently, there are a number of different methods now used in the foundry industry, despite our knowledge of the benefits of using uniform cost-finding principles. The various steps included in these job-cost systems are not always accompanied by explanations showing the reasons for doing certain things, that is, the relation of theory to practice is not always indicated definitely. In the method of calculating the costs of individual steel castings described in the following paragraphs, each step is explained in order to show the logic used in developing the method. The explanatory matter may cause the method to appear complicated, but in reality, it is very simple.

For the consideration of the subject of calculating costs of individual castings in a jobbing foundry, it is necessary to differentiate between it and the subject of monthly cost summaries, because the latter consist of the average costs for thousands of castings made from hundreds of different patterns. Therefore, it is essential that there be concentration on specific castings, and an endeavor to apply indirect expense and overhead expense equitably to those castings. Some fundamental facts having a bearing on this subject are mentioned below.

1. Monthly cost summaries are useful for job-cost purposes only to the extent of providing the basic data required for calculating costs of individual castings.

2. Monthly cost summaries for a jobbing foundry represent the average cost of making hundreds of different kinds of castings, and it would be difficult to select a single casting whose cost would be that represented by the average cost of all the castings made during the period covered.

3. Indirect expense and overhead expense should be applied to an individual casting in a practical manner as nearly as possible according to the amount of such expense consumed in making the casting; that is, there should be a logical and practical basis for applying this expense.

4. The cost of metal differs for castings having different yields. For example, the cost of metal per ton or per pound of good castings for a 50-pound casting requiring 40 pounds of metal in the form of heads and gates, is greater than that for a 50-pound casting requiring 15 pounds of metal in the form of heads and gates.

5. Aside from the cost of making and handling metal, there is but little expense that depends entirely on the weight of a specific casting regardless of its design.

6. The design of the casting and the equipment for quantity or small production govern the cost of making it.

7. Costs per ton used for general cost-accounting purposes have no relation to costs for individual castings. The former are averages made from a large number of the latter. If some items of expense are charged into the general costs at a fixed

rate per ton—and this is done for convenience or because there is no other suitable method—it does not signify that such items should be charged to individual castings in the same manner.

8. The cost of making an individual casting is constant provided the same method of manufacture is used, the efficiency of labor is the same, and the same prices are paid for labor and material. In other words, the cost of making a specific casting is no greater when the foundry is operating at 20 per cent of its capacity than it is when operating at 90 per cent of its capacity. However, the total foundry cost per ton for the entire output is greater when operating at 20 per cent of capacity than when operating at 90 per cent of capacity; but this is due to economic conditions, and the higher cost per ton of the reduced output contains the cost of unused productive capacity. The latter ought to be distributed over all the units of product made during a period including average business conditions, and cannot equitably be charged to the product made only during a period of reduced output.

9. There are two main classes of expense, fixed expense and variable expense. The fixed expense constitutes those items whose total amount remains the same regardless of production, such as salaries, taxes, insurance, etc. The variable expense constitutes those items whose total amount varies with the rate of production of the foundry, such as the productive department expense.

The job-cost method described in this paper is based on the following expenses considered as variable: metal department expense, molding department expense, core department expense, and cleaning and heat-treating department expense, all with the exception of supervision. The fixed or constant expenses, therefore, consist of all the expenses of the business except those regarded as variable expenses, with the addition of all departmental supervision. It is true that some of the items listed as being constant are variable, but they represent a very small proportion of the total constant expense, and for practical purposes they may be considered constant. For example, power is a variable expense, but there is generally no practical and equitable method for prorating the cost of power to the productive departments, and

nothing is gained by doing it arbitrarily. The cost of compressed air which is frequently the largest factor in the power cost, is very difficult to prorate. The amount of electric energy used in each department for driving motors and for lighting is impossible to ascertain without watt-meters in each department. Another item partly variable, although considered as constant in this case, is depreciation. That part of the total depreciation represented by obsolescence, is constant, and the balance may be variable to some extent. The treatment of the fixed and

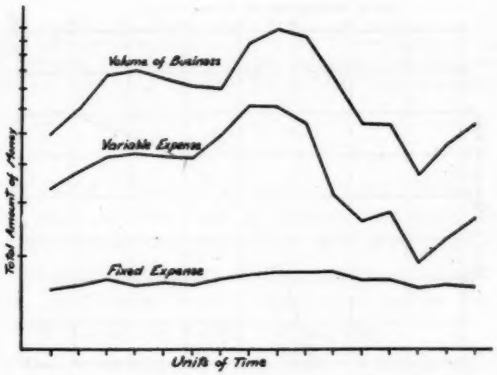


FIG. 3—FIXED AND VARIABLE EXPENSES.

variable expenses with regard to their application to individual castings, will be explained later. Figure 3 shows the relation between the volume of business and the variable and fixed expenses of a foundry.

The problem of calculating the actual cost or the estimated cost of a specific casting, may be divided into three important phases. These are: the cost of the steel, the application of the indirect and overhead expense, and the cleaning cost. For each casting whose cost is to be determined, the following data must be obtained: shipping weight of casting, weight of heads and gates used on it, number of castings scrapped, molding direct labor cost, core direct labor cost, and cleaning cost.

(a) *Metal Cost*

The cost of metal per ton or per pound of good castings is not the same for every casting, but varies with the yield of good castings in percentage of metal charged into the furnace. This is illustrated in Figure 4. If 90 pounds of metal is poured into a mold to make a casting having a shipping weight of 50 pounds, the cost of metal in the 50-pound casting is greater than that for another 50-pound casting which required the pouring of only 60 pounds of metal into the mold. Therefore, it is de-

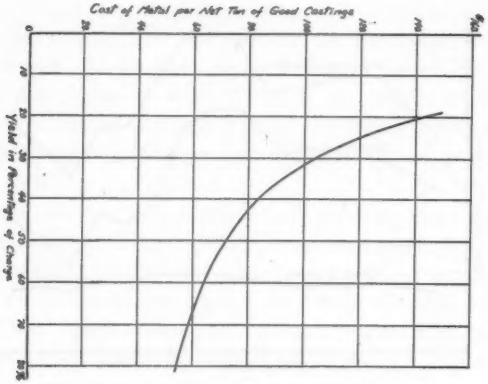


FIG. 4—COST OF METAL FOR DIFFERENT YIELDS.

sirable to determine the yield for the casting whose cost is to be determined. This can be done very quickly by the method described below.

Yield.—The yield is the percentage of toal metal charged into the furnace that results in good castings. To obtain the yield for a specific casting, the following data must be known: shipping weight of the casting, the weight of the heads and gates used on the casting, and the number or weight of the defective castings. The yield can then be calculated from the following formula:

$$\text{Per Cent Yield} = \frac{C\,[100 - (S + L)]}{A + B}, \quad \text{in which}$$

C = shipping weight of casting in pounds.
S = spills and skulls in percentage of the metal charged. This would be obtained from the average of several months' operations.
L = melting and foundry loss (metal unaccounted for) in percentage of the total metal charged. This would be obtained from the average of several months' operations.
A = gross weight of good castings; that is, the shipping weight of good castings plus the weight of the heads and gates used on them.
B = gross weight of defective castings; that is, the weight of the castings scrapped plus the weight of the heads and gates used on them.

In the above formula, the terms S and L are constant as they represent averages of several months' operations. Therefore, if it is assumed that S = 3 per cent and that L = 10 per cent, the following simple formula is used for calculating the yield for castings from a specific pattern:

$$\text{Per Cent Yield} = \frac{87C}{A + B}$$

Cost of Metal.—The cost of metal per net ton of good castings varies with the yield, and it includes two main items: the cost of metals, and the conversion cost. For electric steel-making furnaces, the latter comprises such expenses as melting department labor, supervision, repairs, electrodes, power for electric furnaces, fuel for drying ladles, and supplies.

Since the percentage of each kind of metal entering into the furnace charge is known, and the market prices of these metals can be readily obtained, the cost of metals per net ton of charge can be calculated in the following manner, assumed figures being used.

	Per Cent of Total Charge	Price per Net Ton	Cost per Net Ton of Charge
Pig Iron	1.00	$34.00	$ .34
Purchased Scrap	70.00	24.00	16.80
80 Per Cent Ferromanganese	1.00	112.00	1.12
50 Per Cent Ferrosilicon	.50	80.00	.40
Shop Scrap	27.50	24.00	6.60
Total cost of metals per net ton charged			$25.26

To the cost of metals per net ton charged should be added the normal conversion cost per net ton charged, in order to obtain the total cost of steel per net ton charged. The average

conversion cost should always be used instead of the actual conversion cost for any single month, because during a period of low output from the furnace, the conversion cost is great; and on the other hand, during a period when the furnace is operated continually, the conversion cost is low. The two conditions are equalized by using the average or normal conversion cost, which can be calculated in the manner illustrated below by the use of assumed figures.

	Average Amount Per Net Ton of Charge	Prevailing Cost Per Unit	Cost per Net Ton of Charge
Power	650 KWH	(*$0.017)	$11.25
Electrodes	22 pounds	$0.10	2.20
Man-hours of labor	5.	.70	3.50
Supplies			2.20
Repairs			.50
Fuel for ladles	8 gallons	.06	.48
Total conversion cost per net ton charged			$20.13

*Average.

In the calculation of the conversion cost, the average cost per kilowatt-hour for a period representing good and bad business conditions should be used. This is because the rate per kilowatt-hour is very much lower during a period when the furnace is operating continuously than when it is operating at a reduced output. The demand charge for power is included in the rate per kilowatt-hour, and it is a fixed expense which must be paid whether the furnace is producing five tons or 500 tons a month. Therefore, an average rate for electric power should be used for job purposes.

Obtaining Cost of Metal for a Specific Casting

To obtain the cost of metal for a specific casting, the yield is calculated from the formula given previously, and the cost of metal is then calculated from the following formula:

$$\text{Metal cost per net ton of good castings} = \frac{100M - P(100 - L)}{Y} + P$$

M = total cost of steel per net ton of metal charged into the furnace in dollars. It is the cost of metals plus the average conversion cost.

L = melting and foundry loss (all metal charged that is unaccounted for in either recovered scrap or castings) in percentage of metal charged into the furnace.
P = value of recovered scrap, in dollars per net ton of scrap.
Y = yield of good castings in percentage of metal charged into the furnace. This is calculated from the formula explained in a preceding paragraph.

If it is assumed that the average melting and foundry loss (L in above formula) is ten per cent of the metal charged, the formula becomes the following:

$$\text{Metal cost per net ton of good castings} = \frac{100M - 90P}{Y} + P$$

The most convenient way to obtain the metal cost for individual castings is to construct a table each month based on market prices of metals and showing the cost of metal for various yields. After calculating the yield for the casting whose cost is being determined, reference to this table will give the cost of metal per net ton of good castings. This table is constructed from the formula given above, and an illustration may make this point clear. Suppose that the cost of steel per net ton of charge (this is M in the formula for metal cost) is $45.39, the value of recovered scrap (P in the formula) is $24.00 per net ton of scrap, and the melting and foundry loss (L in the formula) is 10 per cent. Then our formula for metal cost for various yields is:

$$\text{Metal cost per net ton of good castings} = \frac{2379}{Y} + 24$$

A table such as Table 2 can be constructed in about fifteen minutes from this formula.

(*b*) *Application of Indirect Expense and Overhead Expense to Individual Castings*

The application of indirect expense and overhead expense to individual castings in a uniform manner by all members of each branch of the foundry industry is quite essential if the vast differences in costs, caused principally by different cost-finding methods as shown in Table 1 and Figure 1, are to be prevented. The indirect expense to be dealt with here comprises that for the molding department and the core department. The cleaning department indirect expense is combined with the

Table 2

Cost of Steel Per Net Ton of Good Castings for Different Yields

Yield.	Cost of Steel Per Net ton of Castings.	Yield.	Cost of Steel Per Net Ton of Castings.
20	$143.00	50	$71.60
21	137.20	51	70.70
22	132.10	52	69.80
23	127.20	53	68.90
24	123.20	54	68.10
25	119.20	55	67.30
26	115.60	56	66.50
27	112.20	57	65.80
28	109.00	58	65.00
29	106.10	59	64.40
30	103.40	60	63.70
31	100.80	61	63.00
32	98.40	62	62.40
33	96.20	63	61.80
34	94.00	64	61.20
35	92.00	65	60.60
36	90.10	66	60.00
37	88.40	67	59.50
38	86.70	68	59.00
39	85.00	69	58.50
40	83.50	70	58.00
41	82.10	71	57.50
42	80.70	72	57.00
43	79.40	73	56.60
44	78.10	74	56.20
45	76.90	75	55.70
46	75.80	76	55.30
47	74.70	77	54.90
48	73.60	78	54.50
49	72.60	79	54.10

cleaning department direct expense, and the total cleaning cost and heat-treating cost are treated separately from the other costs.

The molding indirect expense for job-cost purposes consists of all the expense in the molding department except supervision and direct labor. The core indirect expense for job-cost purposes consists of all the expense in the core department except supervision and direct labor. The general overhead expense for job-cost purposes consists of all departmental supervision and all the expenses of the business except those for metal department, molding and core direct labor, cleaning and heat-treating cost, and the molding and core indirect expense. The method of applying these expenses to individual castings is described below.

Molding Indirect Expense.—There are some items included in the indirect expense in the molding department that vary with

the size and design of the pattern, and there are some that vary with the weight of the casting. Hence, it does not seem equitable to charge all the molding indirect expense to a specific casting at a fixed rate per pound or per ton for all castings, and neither is it fair to charge all of it to a casting on the basis of the molding direct labor cost by computing it as a percentage of direct labor. If it be true that some of the indirect expense varies with the weight of a casting and the balance of it varies with the size and design of the pattern (for practical purposes these are measured by the molding direct labor cost of a casting), then the molding indirect expense should be applied to a specific casting by using two bases, namely, weight of the casting and molding direct labor cost. This is done by taking 60 per cent of the total molding indirect expense as a fixed rate per ton for all castings, and by taking 40 per cent of it as a certain percentage of the molding direct labor cost. The method of arriving at these two rates for molding indirect expense to be used in calculating the costs of individual castings is illustrated by the following assumed conditions covering a period of one year. Cost figures for a period of several months or a year should always be used for arriving at these rates.

Total amount expended for molding direct labor is $120,000.

Total amount expended for molding indirect expense (supervision not included) is $200,000.

Total number of tons of good castings produced is 5,000.

The percentage of molding direct labor to be used for job-cost purposes will be $\frac{\text{40 per cent of 200,000}}{\text{120,000}} \times 100$, or 66.7 per cent.

The fixed rate per ton of good castings to be used for job-cost purposes will be $\frac{\text{60 per cent of 200,000}}{\text{5,000}}$, or $24.00.

Core Indirect Expense.—There are no items included in the core department indirect expense that have any relation to the weight of a casting, and for this reason none of this expense can equitably be charged to a specific casting on the basis of its

weight. The amount of core department expense incurred on a casting depends entirely on the design of the casting. It is therefore recommended that all the core department indirect expense (with the exception of supervision which has been transferred to general overhead for job-cost purposes) be applied to a specific casting as a percentage of the core direct labor cost. This applies particularly to small and medium sized castings, as some other basis, such as the weight of the core, might be found suitable for large castings. The latter method, however, would hardly be practicable for small cores.

Cost figures for a period of several months or a year should be used for calculating the core indirect expense rate to be used for obtaining the costs of individual castings. If it is assumed that the total amount expended during a year for core direct labor is $40,000, and the total amount expended during the same period for core indirect expense (supervision not included) is $70,000, then the percentage of core direct labor to be used for job costs is $\frac{70{,}000}{40{,}000} \times 100$, or 175 per cent.

When castings are made entirely in cores and no molds are used, the core direct labor cost is considered as molding direct labor cost.

The core department is to a great extent a service department auxiliary to the molding department. It is one of the necessary departments in the foundry whose services are not required by every casting because some castings require no cores. However, the core department is ready to make cores when called upon to do so; and therefore, castings requiring no cores might be charged with a nominal amount of the core department expense. This would be in the nature of a "demand charge" or charge for the readiness and ability to serve. If the average core department indirect expense is $12.00 per ton of good castings, a certain amount of it, say 25 per cent or $3.00 per ton, might be the demand charge to be added to the cost of those castings having no cores. The "demand charge" will be the minimum cost per ton for core indirect expense chargeable to any casting.

General Overhead Expense.—The general overhead expense, which has been previously defined, is common to the business as a whole, and it is impossible to allocate it to the various departments without doing it on an estimated or arbitrary basis. This procedure is recommended in textbooks on cost-accounting theory, and the recommendation may be justifiable because the nature of many industries is such that it is necessary to allocate the general overhead expense, or part of it, to departments or machines in order to arrive at the cost of the product. However, this theory does not seem to fit the steel foundry, and the arbitrary juggling of figures, while appearing well on paper, "doesn't mean anything." Steel foundries have found it desirable to keep the general overhead expense separate, and apply it to individual castings separately; that is, it is not covered up in the departmental indirect expenses. In this connection, it should be understood that no claim is made by the writer that it is possible to apply general overhead expense to an individual casting in a manner that will give an exact cost. There could be no greater indiscretion than the making of such a claim by anyone. All that can be attempted is the practical application of the expense to individual castings by some method that will give costs thought to be as nearly correct as it is possible to make them, meaning that each unit of product shall bear an equitable share of the general overhead expense.

There are no items included in the general overhead expense that have any relation to the weight of a casting, which means that none of the general overhead expense is greater for one casting than for another solely because the first casting weighs more than the second. This fact is obvious when it is realized that the weight of a casting made in a jobbing foundry is not the predominant characteristic, but it is the design of the casting and number of pieces ordered that determine largely the cost and rapidity of making it. Consequently, it does not seem feasible to charge the general overhead expense to all castings at a fixed rate per ton of castings.

The general overhead expense is, for practical purposes, considered fixed in total amount as will be seen by reference

to Figure 3. During normal conditions of business—when the foundry is operating without wide fluctuations in the number of employees or man-hours—the total amount of money expended for general overhead is constant or nearly so. However, the general overhead expense per unit of product (usually a ton of castings), varies inversely with the number of units produced. This is the chief cause for the fluctuations in the total cost per ton shown in Figure 5. Since the total general overhead is constant, and this expense per ton of castings varies with the productivity of the foundry, it would seem that the general over-

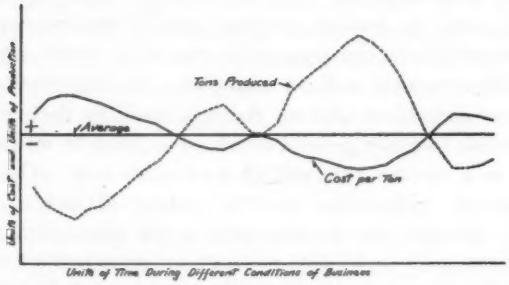


FIG. 5—VARIATIONS IN TOTAL COST PER TON WITH BUSINESS CONDITIONS.

head for job-cost purposes varies with that factor which chiefly determines the number of tons of castings the foundry will produce, because it is common to the entire foundry and cannot be applied directly to specific units. It ought to be charged to individual castings on the basis of their rate of production.

In a jobbing foundry the total number of tons produced may vary considerably without any changes in the total number of man-hours of work expended. This is due to the nature of the castings produced, as there are some fast-moving and some slow-moving castings. Notwithstanding the variety in the classes of castings made, it is not uncommon for the law of averages to cause but slight fluctuation in the total number of tons of castings produced in a definite period of time. We are

not concerned with averages, however, because it is the purpose to consider specific castings.

The molding department is the main productive department in the foundry, and the output of the foundry depends upon the output of the molders. This is quite well recognized, inasmuch as the number of tons of castings produced is the number of tons of metal poured into good castings. The core department, while a productive department, is really a service department, since all castings do not require cores. It cannot be considered as a factor that ordinarily governs the output of the foundry. The cleaning department sometimes is the bottle-neck of the foundry, and becomes plugged due to faulty molding practice, poor management, or improper layout and facilities. However, its function is to prepare for shipment the castings that have been produced, and it cannot be considered as having an influence on the rate of production.

Since the output of the molding department limits that of the foundry under normal conditions of supply and demand, the molding direct labor for a specific casting is a measure of its rate of production, and the general overhead expense might be applied to a casting on this basis. The molding direct labor is variable for different castings, and some castings may be produced at the rate of 300 pounds per molder-hour, while others may be produced at the rate of 50 pounds per molder-hour. The productivity of the first class being greater than that of the second class, it is palpable that the general overhead expense per ton of castings should be less for the first than for the second, because the general overhead expense being practically constant in total amount, varies inversely per ton of castings with the rate of production. By applying this expense to a specific casting as a percentage of its molding direct labor, the distribution of it on the basis of productivity is accomplished, and fast-moving or low molding direct labor jobs will properly be charged with a less amount of the general overhead than will slow-moving jobs.

Careful judgment must be exercised when establishing the general overhead in percentage of molding direct labor to be

used for job costs. The cost figures from which this percentage is derived, should represent the average of good, fair, and poor business conditions. While no definite rule can be formulated, a simple method might be followed by summing up the total dollars expended for general overhead during a period including good, fair, and poor business conditions, and dividing this sum by the total dollars expended for molding direct labor during the same period.

If it is assumed that the total general overhead expense for a period of years representing good, fair, and poor business conditions is $1,500,000, and the total molding direct labor cost for that period is $240,000, the figure to be used for job-cost purposes is $\frac{1,500,000}{240,000} \times 100$, or 625 per cent of molding direct labor.

There is a certain minimum general overhead cost per ton of castings that should be taken into consideration when calculating the cost of a casting. If the general overhead expense is $40,000 a month when the foundry is producing 500 tons a month, the cost per ton is $80.00. If it has been decided that 500 tons of castings a month is a desirable capacity for the foundry, it would probably be possible to produce about 700 tons of fast-moving (low direct labor) castings with the same equipment and organization. The general overhead expense for 700 tons production would then be about $\frac{42,000}{700}$, or $60.00 per ton, which would be the minimum general overhead expense for any casting. This minimum cost per ton would be used when the general overhead cost obtained by computing it as a percentage of the molding direct labor for a certain casting, is less than the minimum. For example, if a casting has a molding direct labor cost of $7.00 a ton, the general overhead expense is 625 per cent of $7.00 or $43.75; but this is less than the minimum of $60.00 a ton, and hence it would not be used, but $60.00 would be used in its stead.

(*c*) *Average or Normal Overhead Costs*

Average or normal costs have been mentioned in this paper in connection with the establishing of the data necessary for computing the cost of individual castings. They mean the costs represented by average conditions of business, and they should always be used when establishing data to be used for estimating costs and for determining actual costs of specific castings. This holds true whether or not normal costs are higher or lower than the actual prevailing costs of carrying on the business during the various stages in the ebb and flow of the demand for castings caused by continually changing economic conditions.

The expense logically chargeable to a casting is that required for its manufacture when the plant is operated at average or normal capacity, because the actual effort and use of the foundry's facilities required for making a casting are no less when the plant is operating at maximum capacity than when it is operating at a reduced rate, providing all other conditions are equal. The total cost for the entire foundry per unit of output is low during abnormal business conditions, and is high during subnormal business conditions. The principal reason for this is that the general overhead expense or fixed expense (see Figure 3) is distributed over a different number of units of output, usually tons in a foundry. However, this does not mean that the cost of making an individual casting varies with the rate of production for the entire shop; that is, it is not affected by business conditions in the same manner as the total foundry cost per ton is affected. Therefore, the overhead rates for use in obtaining costs of individual castings must be computed from a summary of costs representing average business conditions.

Figure 5 illustrates the influence of periods of depression and prosperity on the total foundry cost per ton of castings produced. The horizontal or normal line represents the average cost to be used for the computation of overhead rates necessary for determining job costs. It is very essential that this principle of using average costs, representing good, fair, and bad business conditions, for the computation of overhead rates and par-

ticularly the rate for the general overhead or fixed expense, be used in practice. This is necessary in order to provide sufficient surplus net profits during a period of business activity to prevent financial starvation during a period of slackened demand for castings; or in other words, the difference in the form of a surplus between normal and actual costs during prosperity must be equivalent to the difference in the form of a deficit between normal costs and actual costs during business stagnation.

If the foundry endeavored to market its castings at prices based on the actual prevailing costs during depressed business conditions, there would be difficulty in doing it, as consumers could not be expected to pay the high prices that would be quoted because they are not responsible for the high cost due to idle capacity. On the other hand, the foundry would have little difficulty in marketing its castings at prices based on the actual prevailing costs during a period of prosperity, because the costs would be low. However, the latter would be too low and would not cover the excessive cost incurred when the foundry is operating at a reduced rate of capacity. The two extreme conditions of prosperity and depression that occur from time to time, are equalized by the use of overhead rates for job-cost purposes, calculated from the average costs for good, fair, and poor business conditions in a foundry.

(*d*) *Additions to Job Costs for Defectives*

Molding.—When calculating the cost of a casting, the amount of defective castings, if added to the molding direct labor cost in the form of a percentage, should always be stated as a percentage of the good castings. It should never be a percentage of the total castings, meaning the sum of the good and the defective castings. The examples on the next page illustrate this point.

Example (a) shows the actual molding direct labor cost per good casting after making the proper allowance for the castings that were scrapped. Example (b) indicates the same cost as that in example (a) and illustrates the point that when additions are made for defective castings in the form of a percentage, the scrapped castings should be in percentage of good castings,

Examples to Show Additions to Job Costs for Defectives

Number of good castings made	20
Number of castings scrapped	4
(a) Molding direct labor cost at $0.40 each for 20 castings is	$8.00
Molding direct labor cost at $0.40 each for 4 defective castings is	1.60
Total molding direct labor cost is	$9.60
Total molding direct labor cost per good casting is	$ .48
(b) Adding defective castings as a percentage of good castings:	
Molding direct labor cost per casting	$ .40
Addition for defective castings—20 per cent of $0.40	.08
Total molding direct labor cost per casting	$ .48
(c) Adding defective castings as a percentage of total castings made:	
Molding direct labor cost per casting	$ .40
Addition for defective castings—16.7 per cent of $0.40	.067
Total molding direct labor cost per casting	$.467

and not in percentage of total castings as shown in example (c) which gives an incorrect cost.

Core.—The percentage of good castings represented by defective castings is added to the core direct labor cost in the same manner as it is added to the molding direct labor cost.

The average amount of core breakage and wastage for the entire output of the foundry should also be added to the core direct labor cost of every casting. There is always a certain amount of core breakage in a foundry, and an addition ought to be made to the cost of every casting to cover this expense, because it is not included in the overhead cost. The average core breakage is added to the cost for a specific casting by adding to the actual core direct labor cost for that casting a certain percentage of it. If it is assumed that this average core breakage for the entire output is 10 per cent, the following example illustrates its use in job costs.

Number of good castings made	20
Number of castings scrapped	4
Amount of defective castings in percentage of the good castings is then 20 per cent.	
Core direct labor cost per casting	$ .10
Addition for defective castings—20 per cent of $0.10	.02
Core breakage—10 per cent of (.10 + .02)	.012
Total core direct labor cost per casting	$ .132

(e) Addition to Job Costs for Returned Castings

The average amount of castings returned by all customers is included in the general overhead expense, and is consequently charged to every casting whose cost is calculated. However, the returns for some castings are excessive, and an addition ought to be made to the total costs of those castings in order to cover the extra hazards in making them.

If the average amount of returned castings for all jobs is 3 per cent of the total—which is included in the general overhead expense and charged to every casting—and the returned castings from a certain pattern amount to 8 per cent of the total castings made from that pattern, then 5 per cent (8 per cent minus 3 per cent) of the total cost of those castings ought to be added to the total cost.

(f) Cleaning and Heat-Treating Costs

The cost of cleaning a specified casting, especially a small steel casting, is the most difficult to obtain of all the elements of cost in the foundry, without employing a force of timekeepers in the cleaning department. It depends on the design of the casting and on the condition of the casting when received from the molding department.

The cleaning and finishing department of a steel foundry is somewhat like a machine shop, in that each operation has a distinct cost per unit of time for labor and material. The most important of these cleaning operations, so far as costs of labor and material are concerned, are removing heads and gates, grinding, chipping, and welding. The costs of blasting and tumbling are of less importance and might be charged to all castings at a fixed rate per ton because there is less variance in these costs than in the costs of the other operations when considering individual castings of small and medium sizes.

A suggestion is offered that statistics be accumulated in each foundry on the various cleaning operations required on different classes of castings. Such statistics will serve as a guide for arriving at the cleaning cost of a specific casting. They should be obtained preferably for such operations as re-

moving heads and gates, grinding, chipping, and perhaps welding, since these are separate and distinct operations, each having a separate cost per unit of time for labor and material.

It is the practice of many foundries to charge the cost of cleaning to all castings at a fixed average rate per ton of castings. This is not always correct, because the weight of a casting does not govern its cost of cleaning. If the average cleaning cost is $35.00 per ton of castings, there may be some castings whose actual cost of cleaning is only $15.00 per ton, and on the other hand, there may be other castings whose actual cost of cleaning is $80.00 per ton. In lieu of statistics on the cost of cleaning specific castings which could be used as a basis for comparison, the foundryman ought to estimate the cleaning cost of a casting by careful consideration of its design and by the use of judgment based on his experience; that is, the average cleaning cost per ton for the entire output might be varied to suit the casting whose cost is being determined.

The cost of heat-treating steel castings in a jobbing foundry is another item difficult to charge accurately to a specific casting. Theoretically, it would seem that the cost of heat-treating depends solely on the weight of a casting and the thickness of its sections, since the amount of heat units required depends on the weight of the steel to be heated and the thickness of the metal sections whose structure is to be refined. The basis of weight of the casting might be a suitable one to be used for charging individual castings with the cost of the heat-treating, although it is not exact because of the wide variation in practice in the relation between the volume of the load in the furnace and its weight, caused by variations in the designs of the castings being heat-treated.

(*g*) *Cost Calculation for a Specific Casting*

The application of the cost-finding practice recommended in this paper, is illustrated by using the following assumed data which would be obtained from the accounting statistics:

Spills and skulls = 3 per cent of metal charged into furnace.
Melting and foundry loss = 10 per cent of metal charged.

Then per cent yield $= \frac{87C}{A+B}$ refer to the section of this paper on the subject of "Yield."

Total cost of steel per net ton of charge = $45.39.

Value of recovered scrap = $24.00 per net ton of scrap.

Metal cost per net ton of good castings $= \frac{2379}{Y} + 24$. (refer to the section of this paper on the subject of "Metal Cost").

Molding indirect expense = $24.00 per net ton of good castings plus 66.7 per cent of molding direct labor.

Core indirect expense = 175 per cent of core direct labor.

General overhead expense = 625 per cent of molding direct labor, with a minimum of $60.00 per ton of castings.

Average amount of returned castings = 3 per cent of output.

Core breakage = 10 per cent of core direct labor.

The use of the above data for calculating the cost of a casting is illustrated in the example on the next page.

In this example it was unnecessary to use the minimum general overhead expense because that obtained by computing it as a percentage of the molding direct labor cost is greater than the minimum.

The total cost of a casting may be quickly obtained from a chart such as Figure 6. This is a simple line chart which can be constructed for any combination of cost data in a very short time, by using the method of plotting an equation containing five variables. This chart was drawn by using the basic data necessary for job costs that was given at the beginning of this section.

The use of the chart for calculating the cost of a casting is the following:

For each casting whose cost is being determined the known data are: metal cost (obtained from Table II), molding direct labor cost per ton, core direct labor cost per ton, and cleaning and heat-treating cost per ton. The chart eliminates the calculations for indirect expense, general overhead expense, and addition for core breakage. Connect the points on the metal cost and the molding cost scales with a straight-edge, and mark the point of intersection on line A. Connect the points on the core cost and cleaning cost scales with a straight-edge, and mark the point of intersection on line B. Connect the two points on

Example to Illustrate Use of Cost Finding Practice Recommended in This Paper

Shipping weight of one casting.....50 lbs.
Weight of heads and gate on one casting.....20 lbs.
Number of good castings made.....20
Number of castings scrapped..... 4
Molding direct labor cost per casting..... $ .40
Core direct labor cost per casting..... .10
Cleaning and heat-treating cost per casting..... 1.50
Returned castings—8 per cent of castings shipped on previous orders for these particular castings

The yield is $\frac{87\ (50 \times 20)}{20\ (50+20)+4\ (50+20)} = 52.\%$

Reference to Table II showing the cost of steel per net ton of good castings for various yields, shows the cost of steel for a yield of 52.% to be $69.80 per ton of castings.

	Cost per Casting	Cost per Net Ton of Good Castings
Metal cost	....	$ 69.80
Molding direct labor cost	$ .40	
Addition for actual defectives—20% of .40	.08	
Total molding direct labor cost	$ .48	19.20
Molding indirect expense—66.7% of 19.20		12.81
—24.00 per ton		24.00
Core direct labor cost	$ .10	
Addition for actual defectives—20% of .10	.02	
Core breakage—10% of .12	.012	
Total core direct labor cost	.132	5.28
Core indirect expense—175% of 5.28		9.24
Cleaning and heat-treating cost		60.00
General overhead expense—625% of 19.20		120.00
Total		$320.33
Addition for returned castings—5% of 320.33		16.02
Total cost		$336.35

lines A and B with a straight-edge, and the point of intersection with the total cost scale gives the total cost per ton for making the casting.

VI.—Conclusion

Foundrymen should receive much benefit from the diligent and regular study and use of total costs and costs of individual

castings computed by means of uniform cost-finding principles. The returns may be many times those that might accrue from the study of any other single phase of the business, perhaps with the exception of personnel and organization problems. While nickels might be saved from the devotion of time and energy to some detail of manufacturing, perhaps dollars would be saved if the subject of cost and operating data is given the same degree of thoughtful attention and analysis. There is

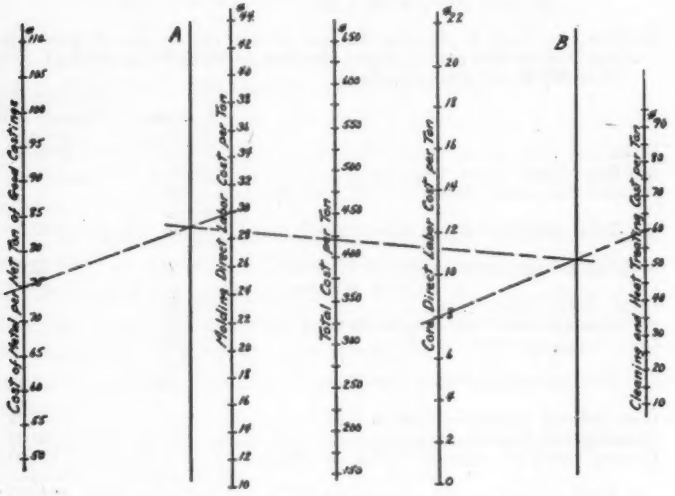

A
B
Cost of Metal per Net Ton of Good Castings
Molding Direct Labor Cost per Ton
Total Cost per Ton
Core Direct Labor Cost per Ton
Cleaning and Heat Treating Cost per Ton

FIG. 6—GRAPHIC COMPUTATION OF COSTS.

probably no detail of the business of greater importance than the latter. In order that a foundry may accomplish the one thing for which it exists—interest on capital, it must be kept on its course by the use of costs just as a ship is kept on its course by the use of a rudder. Without costs in a producing foundry, and without a rudder on a moving ship, there is much dependence on Providence or on the mercy of opposing influences for reaching the desired destination.

Discussion—Cost Finding in a Foundry

By C. W. GRANT, Pittsburgh, Pa.

The author of the paper on this subject, Mr. Corbett, should be given considerable credit for the manner in which he has dealt with the details and the distribution of burden, or overheads, from the viewpoint of the foundries which he represents. However, I believe there is more to be said regarding "Uniform Methods of Cost Finding in a Foundry," and especially the application of overheads to job costs from the viewpoint of foundries manufacturing a heavier and more variable grade of castings.

Uniform methods of cost finding in regard to a particular industry, no doubt, result in better informed competition, reveal individual products which are unprofitable and provide better guides for economy and efficiency, but the fact should be constantly borne in mind that different operating conditions exist in different plants and uniform methods should not be carried beyond their practical limitations; for instance, it is good practice for all foundries to distribute labor and expense to the same classification of accounts, but their application to an individual casting might be vastly different, depending upon the class of work and the foundry practice employed at different plants.

Distribution of Molding Overhead.

I believe the majority of foundrymen and cost authorities consider the molding direct labor an equitable basis for the distribution of molding indirect labor and expense, and I am of the opinion that this is true to the extent of such items as vary with the design of the casting. These items of expense bear a close relation to the direct labor, but the items which vary with the weight of the casting should be applied on a

per net ton basis, if there be any, and I do not believe that any fixed percentage would divide the items in an equitable manner to suit all foundries.

It might be more practical to make separate lists of those expense items which are related to the direct labor and those which vary with the weight of the castings and let each foundry apply the cost of each item and establish their own division upon which to form their basis for estimating job costs, as the basis for dividing these items of expense to a large degree depends upon the molding equipment used and the practice of each foundry.

Core Overhead.

Indirect labor and expense of this department is usually distributed on the basis of its relation to the direct labor of this department. However, I do not believe it quite fair to use a demand overhead charge on jobs having little or no core-making.

A core department in a steel foundry cannot be compared with a public utilities company furnishing current for industrial purposes. If the class of castings being produced does not warrant the operation of the core department to full capacity, its degree of operation is immediately cut down as far as requirements will permit, whereas, a plant producing power may be demanded to deliver a maximum amount of current instantly without notice.

Core direct labor, used as molding direct labor, and applying molding department overhead to a job made entirely in cores. This method seems to charge more than a normal overhead to this class of work. The foundries making a heavier class of work find that there is a greater spread between the molding and core overhead on the heavier class of work than there is on the lighter grades of work.

Cleaning and Finishing Cost.

I believe that from the standpoint of a foundry producing small light section castings, that the author has treated this phase of the cost to the best advantage, but from the stand-

point of a foundry producing a heavier and more variable grade of castings, it would tend to further complicate the method generally in vogue. It is sufficiently difficult to estimate the direct labor of cleaning and finishing without having to estimate the indirect labor and expense and from the latter viewpoint, I believe it better practice to estimate the direct labor for each operation (especially where such operation is on a piecework basis) and apply the overhead by the per cent relation it bears to the direct labor.

General Overhead Expenses.

It is a recognized fact among foundrymen that the weight of a casting has little to do with the variations of this phase of the cost, because the amount expended for general overhead expenses remains almost constant under normal production.

I believe it is hardly fair to transfer the cost of supervision of the main productive departments to the general overhead expense for application to job costs, as its relation to the direct labor of the department in which it is chargeable seems to be a more equitable basis upon which to apply it.

From the standpoint of a foundry making a varied line of average weight castings of 500 pounds and upwards, it seems more practical to apply the general overhead expense on the basis of molding and core direct labor instead of on molding direct labor only, because there are few castings in this range which do not require some cores in method of manufacture and the castings requiring an abnormal amount of core labor would get by with less than the proportion of general overhead expense which should be charged to a casting of this nature.

Throughout this discussion I have endeavored to point out briefly those phases of costs which I believe should receive further consideration before a uniform cost system could be accepted universally by all foundries and submit it to promote progress of uniform cost methods.

Discussion—Cost Finding in the Foundry

S. L. DRYFOOS: I think that the difficulty of costs is rather an argument between cost members themselves than one of principle. I believe costs can be obtained every month so that you know actually where you come out, but it seems to me that you ought to know on each individual job just how profitable it is before waiting till the end of the month, and if you make all your calculations properly, as regards moldings, your job will come out properly as a profitable job. I think you can do that on a square foot basis better than an average basis; that is, a square foot basis of your shop, distributing your overhead on area rather than molding or direct labor. We do that in our shop, and we know after each job is done whether we have made a profit on that job or not and at the end of the month we know whether we have estimated correctly on absorbing our overhead or not. We are willing to give you at any time our method, if it will aid you in arriving at a uniform and practical method for foundry use.

A. E. HAGEBOECK: When you speak of direct molding as a means of distributing your overhead, do you mean the direct molding dollars or the direct molding hours?

W. J. CORBETT: Dollars; for the reason that in a good many foundries the piecework system is used for paying molders and it is easier to get the cost.

H. J. KOCH: If I get the paper right, it is not absolutely the recommendation of the adoption of a uniform system as much as to show the need of it in our merchandising, eliminate unprofitable work and stop our kicking. Was that one of the purposes?

W. J. CORBETT: Yes, more to create the desire for uniform cost finding principles, and in advocating the use of a uniform cost system, I felt that it was necessary to give a cost system.

H. A. NEEL: I would like to ask the gentleman who advocated the distribution of overhead on a square foot basis, whether he does not put in any factor excepting the productivity of that square foot? That is, given two molding floors of equal size, side by side, one of which is producing three tons of castings a day and the other is producing a thousand pounds of castings per day, does each bear the general overhead burden simply because they happen to be of equal area?

S. L. DRYFOOS: I will answer that in this way; I think they both do. Your area basis would mean that you have to take a certain profit per floor, your floor area must be determined in advance as to what is a fair size; the man who makes a thousand pounds per day

on the floor does not make sufficient profit, comparable with the next man who makes three thousand pounds; there is a certain basis on which you must figure a profit per square foot or on direct labor in the shop, but the objection to direct labor is this; you might have a man on this floor who is earning $6.00 a day and a man on the next floor who is paid $10.00 a day and who is worth $10.00; your overhead on one man is a great deal more than on the other. The thousand pound job is a more profitable job to you, and in order to make up that difference you are adding an extra man on the thousand pound floor. You have to figure a certain basis of profit per floor the same as if you were renting that out, and if a man takes more than one floor in a day to work and is a $10.00 man, you have to charge him up with the extra space he uses. I saw an example the other day in per hour wages, where they found one job figured out on the average basis of five and three-quarters. On one job the casting was sold by a man who had a very good system at twenty-one cents a pound. Another fellow figured out by averages and sold them at fifteen cents a pound. His method showed that he was figuring right. The confusion is this, that cost is figured as a post mortem, in most cases, whereas you ought to have a definite system of figuring in estimating what your cost is actually going to be. After you have figured and know that your cost is very nearly true, you know whatever profit you add will be an actual profit. Whereas figuring your averages, you are not just sure.

With a definite system if you pay a man $6.00 or $10.00 a day, you pay that exactly and say that that man must make 150 molds a day; if he makes less, you are losing on that man. With this average system of wages, you can immediately see what is happening. The worst part is this, you take the thousand pound job, molder might produce enough in that thousand pounds, and probably he would, to take another man two days to grind up and clean what he made in one day, whereas the fellow who made the three thousand pounds, his work would be cleaned and ground and ready to be shipped in two or three hours after it goes into the cleaning room. The thousand pound job has had probably twice as much cleaning and grinding as the molding labor expended on that particular job.

In our foundries we take the cleaning expense the same as direct labor, and charge that to that particular job, with the result that that job stands for the operation of everything that is put on to that job, and we establish that price and stick to it.

I will illustrate that this way; we were selling a very large concern on average prices that amounted to fifteen cents a pound. This is an exact example and by averages it showed that our prior cost was about twelve cents. We figured that we were making a fair profit on that job. We changed our system over to the floor basis, established the production which a man had to make and the rate paid by the mold,

and found that that job should sell for thirty cents a pound. The cleaning time was all figured in on that, and we quoted this man thirty cents a pound and showed where that figure was obtained, with the result that he is buying those castings for thirty cents a pound and knows that it is just a fair price. We had been fooling ourselves with fifteen cents a pound previous to that, and the buyer would have been perfectly willing to pay thirty cents, but we did not know the difference. We would have been better off without the job at fifteen cents in our plant. There are many others of that same nature, and we probably would have made more money, but we were just deceiving ourselves. The man was a perfectly fair buyer and was perfectly willing to pay thirty cents, but we did not know that thirty cents was right, so now we have a system that we think is pretty near correct. I do not think we obtain a correct average on all classes of work, when we do very light work and when we do very heavy work.

H. A. NEAL: It seems to me that the big difference between these two papers is this, that they have approached the subject from two slightly different angles. Mr. Corbett's paper, as I understand it, was intended to get down to the very definite question of the cost of an individual casting, whereas Mr. May has been more general in his statements and has confined himself more to the question of the cost of operating a department without laying out an exceedingly definite plan of applying those costs to the individual job. In other words, Mr. Corbett has tried to give us something which would serve as a basis for the work of the sales department. Now on the first page of Mr. May's paper, he gives four reasons for the continuation of unprofitable lines of foundry work. He says further that it is of the greatest importance to the foundryman to know just how far he can go with these unprofitable lines. Well, I might say on that subject, that the financial graveyard is full of foundrymen who went just a little bit too far. It is undoubtedly the biggest question that the foundry industry has to face today, the question of merchandising. There has been a wonderful evolution in the last few years from the old flat tonnage basis, first to a schedule basis, and now to an individual piece basis. It is absolutely essential that costs be prorated accurately to the individual job, and I think it is most essential that the sales departments of the various foundries make up their minds not to carry certain lines that they know are unprofitable, but to put all their production as nearly as possible on a profitable basis, in fairness to your customer, if you were carrying certain work that you know is unprofitable and you are overcharging the man who gives you profitable work, if you are realizing adequate returns on the total value of your work. It is fair not only to the foundry, but it is fair to the customer to make every job stand on its own feet. If a man wants a very difficult intricate casting, even though ninety per cent of his work may

be plain, he should pay the price for the intricate casting. Now the old theory was that you sugarcoated that price by just tacking on a little more to the plain work, but it would be a much more businesslike arrangement right straight through if we made up our minds that each job should pay what it was worth, then we would not be under the obligation of finding out just how far we could go with unprofitable work.

C. H. Ross: I would like to ask a question regarding a safety plan on preparing the cost schedule on a new job before you have run it; for instance, you may pick up a blueprint and determine that that job would run through the foundry operation with very little loss; probably you say two per cent would be your greatest loss, and by the time you have run it through, you have had five per cent loss. I wonder if these various papers have taken into consideration the safety factor; that is, if you have figured everything, shall you add a definite percentage to save your neck?

H. A. Neal: In our own foundry, of course, we do a lot of estimating work, and we do not use any percentage safety factor; we analyze a blueprint, and if we are firmly convinced that the defectives will run higher than the normal defectives, we have a percentage excess which our judgment tells us will occur. If it is a job in which the customer's returns are likely to exceed your average returns, we add a percentage for that, but I do not believe it is possible to introduce any definite two or three per cent insurance policies, because the foundries have to carry their own insurance, the customer will not.

S. L. Dryfoos: I had not read Mr. May's paper when I spoke about the square foot basis; we debated that and endeavored to analyze the method. Our method is very similar to Mr. May's article, except that he uses a square foot basis, but that is practically the same as the machine hour basis. You can analyze both just about the same, so our method is very similar to the analysis given by Mr. May. We figure that from experience we know from a similar job about what the loss will be. We say our loss will be two or three or five per cent, or whatever we may determine, and we watch the stock report on that, and then we have a correct basis on which to figure that stock percentage and figure that in the cost.

H. J. Koch: I was on the committee which originally endeavored to get up the cost system to which Mr. May referred. I might state that since then there has been some evolution in cost finding, and I think it has been more along the line as brought out by Mr. Neal. At that time the feeling in the committee was a great deal as expressed by Mr. May where he says that detail costs are not alone necessary for the establishment of selling prices, but are far more important as an aid to managerial control. Today there has been so much ruinous competition, all foundrymen, brass, iron, steel and everybody, are kicking on low prices and the trend has been to use cost finding, as

Mr. Neal says, on individual castings, to be able to somehow control our sales departments and the prices which we put on castings. The old idea used to be that if we made five hundred tons of castings, we expected a profit on three hundred tons; we expected to break even on a hundred tons and lose on a hundred tons. Many of the more aggressive foundries today are working along the line to cut out that loss on the hundred tons of castings. If you do not, you only have a net profit on two hundred tons of castings, and yet you think and know you have been making five hundred tons. I think that is the difference largely between these two papers. Mr. Corbett tries to not justify any unprofitable order. Mr. May seems to think that we still have to make unprofitable business for the sake of tonnage.

H. B. MAY: In some plants that is still necessary; they probably have not developed their business to the point where they can tell their customer, "We will not take that class of work." For example, I was recently in a large brass foundry; they have practically all of their product on a production basis. When I say a production basis, I mean through their foundry, through their machine shop and all through their process of manufacturing, they are handling it on a volume basis, consequently they can have tools automatic and semi-automatic. They get a good many orders from their old customers who insist on this or that peculiarity in the design. In years back when this concern began its business career they built their business on serving their customer, giving him what he wanted. They cannot charge this customer or that customer what the chief castings cost them to produce, or what the finished part cost them to produce, for the simple reason that the costs are so far out of line with their regular process goods that to charge the customer that excessive price would mean losing the customer. Of course, they have tried to bring about a higher price for these articles that are not standard, but most of us realize that this is impossible in all cases. However, there is a tendency on the part of most manufacturers to obtain a fair profit on all lines of goods. I do not say that in justification of the fact I have referred to, but there is a condition existing in some plants, and I would like to say further that this cost system also includes the figuring of costs on individual jobs, they apply that and determine the cost on the actual job that goes through the shop, so it is really reaching the end Mr. Corbett is aiming at in his paper. I did not give a complete description of that because the paper would not permit it and to have gone into the discussion of how we figured costs would have meant that it was necessary for me to rehash a lot of material that is now of record with the Association. However, by referring to volume 28 of the Transactions of the A. F. A. the complete description of our method of figuring individual costs may be obtained.

Progress Report of Joint Committee on Pattern Equipment Standardization

To the Members of the American Foundrymen's Association:

The Joint Committee on Pattern Equipment Standardization, sponsored by the American Foundrymen's Association, is made up of two representatives from each of the following organizations:

American Foundrymen's Association.
American Institute of Mining and Metallurgical Engineers.
American Malleable Castings Association.
American Society for Testing Materials.
Foundry Equipment Manufacturers Association.
National Association of Pattern Manufacturers.
National Association of Purchasing Agents.
Steel Founders Society of America.

In addition, there are three sub-committees, each comprising a chairman and four or five members. As far as possible it is sought to have each sub-committee consist of a representative from each of the following branches of the foundry industry:

Gray iron.
Steel.
Malleable.
Nonferrous.
Automobile.

The work was actively begun in June, 1924, under the direction of the general chairman. It has been divided into three general sub-heads, as follows:

1. Pattern Making.
2. Pattern Plates and Mounting.
3. Flask Sizes and Details.

A sub-committee deals specifically with each subject. Questionnaire sheets in the form of drawings have been prepared showing tentative proposed standards for criticism first by the respective sub-committees, then by the general committee when

the details are ready to be submitted to the latter. The criticism and approval of a considerable number of representative shops will also be sought before the proposed standards are finally passed upon by the general committee and recommended to the trade for adoption. Such is the general plan.

Meetings of the three sub-committees and the general committee were held at Milwaukee during the convention of the American Foundrymen's Association in October. These meetings were called primarily to discuss the questionnaire sheets aforementioned which had been criticised individually by sub-committee members. The sub-committee meetings were satisfactory but the general committee meeting was too sparsely attended to have a working quorum.

Under the sub-head of Pattern Making, the subject considered for standardization was the uniform color markings for the various parts of patterns and coreboxes. The questionnaire sheets submitted by the general chairman were discussed at the meeting of Sub-committee I, and the following color markings were agreed upon for all wood patterns and coreboxes, the corresponding parts on the two to be colored alike:

Surfaces to be left unfinished—Black.
Surfaces to be machined—Red.
Seats for loose pieces—Red stripes on yellow background.
Stop-offs—Black diagonal stripes on yellow background.
Coreprints and cut-throughs—Yellow.
Stop-offs—Black diagonal stripes on yellow background.

Sub-committee I was of the opinion that the above colorings are as simple and practical as can be devised and thought it unnecessary to submit them to further criticism. Hence it was agreed by all those present at the meeting of the general committee that the color markings decided upon and proposed by Sub-committee I be recommended for adoption as standards.

It was further decided in the meeting of Sub-committee I to consider the question of a uniform taper on coreprints, using the present standards of the Western Foundry Company, Chicago, as a basis. These provide for the same taper on both ends of a round core, three angles being used to cover the range of sizes from O up to 3 inches diameter of core.

Under the second sub-head, Pattern Plates and Mounting, the preliminary work was presented in the form of questionnaire sheets, showing a suggested standard design of pattern plate for each size of flask. Three designs, one for each of the three ranges of flask sizes, from 42 inches up to 108 inches, appear. These plates were shown with the flasks in position and were fully dimensioned. The sub-committee members were requested to circle any dimension they might wish to change as well as criticise the general design. These sheets were sent out to the members of Sub-committee II and returned with various comments. At the meeting of this sub-committee, however, only the malleable representative was present, so it was impossible to come to any definite conclusions. It was decided to proceed with the preliminary work on matchplates and call another meeting when more data could be presented and all of the members be present. The subject of pattern mounting seems to loom up as the most difficult of the three on which to reach a decision since the opinions of the sub-committee members seem to be widely diversified. However, a meeting with everybody present should at least clear things up to the extent of giving the general chairman a more definite basis to work from than he had this past summer.

Under the third sub-head, Flask Sizes and Details, questionnaire sheets were prepared and forwarded to members of Sub-committee III. They contained three suggested standard designs of flasks covering the range from 42 up to 108 inches, fully dimensioned as to pin center distances, lugs, trunnions, sections of walls, et cetera. Likewise sub-committee members were requested to circle any dimensions they might wish to change, as well as criticise the general design. For the most part, the latter was approved at the meeting of Sub-committee III. It was decided, however, that the first points to be considered in the standardization of flasks were the range of sizes (length, width, and height), and the center distance of pin holes. This range of flask sizes is being worked up now by the general chairman and will be submitted to the members before the next meeting of Sub-committee III.

At the meeting of the general committee it was decided to

approve the work to date and recommend that the work of the Joint Committee on Pattern Equipment Standardization be provided for and continued. It was further unanimously agreed that a letter of thanks be sent to the American Foundrymen's Association for the active interest it has taken in the work. Up-to-date the A. F. A. alone has stood the entire expense attached to the work in order that it might proceed without delay and with the hope that the other affiliated organizations would become more deeply interested when it was shown to be a worthwhile undertaking. Such seems to be the general consensus of opinion now.

Thus far, then, the Joint Committee on Pattern Equipment Standardization has recommended for adoption a set of uniform or standard color markings for patterns and coreboxes, and has made a good start towards proposing standards for pattern plates and flasks. It remains to get the sub-committees to come to an agreement concerning these latter, so that the next meeting of the general committee will have definite proposals to decide upon. In the meantime the subject of pattern equipment standardization and the activities of the committee will be given as much publicity as possible in the technical journals and organs of the affiliated organizations.

Respectfully submitted,

E. S. CARMEN, *Chairman.*
H. O. HAUGHTON, *Secretary.*

The Milwaukee Apprenticeship Program

By H. S. Falk, Milwaukee.

Metal trades apprentices in the Milwaukee district increased from 300 in 1918 to 1,000 in 1924. Foundry apprentices increased from 32 in 1920 to 250 in 1924. This splendid showing has been brought about by the excellent spirit of co-operation among the various foundries and machine shops of the Milwaukee industrial community. Several of the larger plants had always carried on apprenticeship work in some measure at all times, but not until recently have the many smaller organizations been enlisted in these training activities. While much development work still remains to be done it can be safely said that never before in the history of this community has the spirit of apprenticeship training so impressed itself upon the individual members making up our industrial family.

Apprenticeship training had progressed to the point in Milwaukee by the beginning of the present year that the metal trades organization saw fit to give definite shape and form to the district program by setting aside funds and ratifying the appointment of a district director, who is to co-operate with the local secretary and work under the general jurisdiction of the apprenticeship committee. This definitely establishes the Milwaukee district apprenticeship plan.

What Is the Nature of This Plan?

As is obvious to anyone engaged in actual metal trades manufacturing, the vast majority of plants are either too small or too specialized in their products or processes to justify a complete course of apprenticeship training. This unfortunately has been only too generally recognized and accordingly accepted, as an obstacle to a plan by which all plants would bear their just burden in maintaining the full quota of mechanics necessary to the industrial independence of a community.

The Milwaukee plan not only recognizes this as a fact, but contains within itself such provisions as will draw all plants, regardless of size into these training activities. A smaller foundry which can neither justify the expense of a training organization, nor, because of lack of diversity, justify a full four-year apprenticeship, can, however, do its full and just share if united to a larger plant for the purpose of co-operatively carrying out a complete program of industrial education, or apprenticeship. In the Milwaukee plan a convenient number of smaller organizations, properly located geographically, are united to a centrally located larger plant. A common schedule of apprenticeship work is drawn up, to which justice can be done by interchanging apprentices between the smaller and larger plants. In other words, where apprenticeship must necessarily fail in the individual plant it can be made successful if a plan of co-operation and interchange be established whereby the work in the smaller plant can be properly supplemented by that in the larger. This in brief is the outline of the Milwaukee plan. Many such groups are being established, a sufficient number, in fact, to make it possible for every plant to participate in this apprenticeship work.

The district director with the local secretary and the apprenticeship committee constitute the governing body to carry on all activities common to the groups as well as the individual members within the groups.

Co-Operation With Local Vocational School

The local vocational school becomes a center about which many of the district activities revolve. In Wisconsin this institution has by law been established as the part-time institution in which the academic studies necessary to modern apprenticeship are carried on. All regularly indentured apprentices, on state contracts, must attend the vocational school one-half day per week during the first two years of their apprenticeship. This has been generally extended throughout the metal trades in Milwaukee to include the full term of apprenticeship. This institution becomes, therefore, the gathering point of all apprentices each week. It provides such academic class-room

instruction as either the small plant could not give or the larger plant would find inconvenient. Complete co-operation has been established between the metal trades organization in its apprenticeship activities and the vocational school authorities.

Apprentices are now sent full time to the local vocational school during a portion or all of their probational period. Half of this time is devoted to the proper shop work, while the other half is given over to related trade class-room study. This has resulted principally in three things: 1st, a reduction in the mortality of probationary apprentices in the plants themselves; 2nd, a better opportunity to properly guide young men in that trade for which they are peculiarly adapted; 3rd, in an alleviation of the inconveniences to shop foremen resulting from the usually large mortality among the probationary apprentices.

There is little or no idea in the full-time vocational school period of teaching even of a portion of any of the trades. This may, however, be a secondary result, since the shop schools are fully equipped and competently manned by skilled tradesmen. The beneficial effects are principally to be found in the general strengthening of the apprenticeship idea, an organized method of inducting young men into their life work and the lifting of the shop burden of breaking in probationary apprentices, which has always been the cause of no little distress and anxiety among foremen.

The local vocational school is fully equipped to carry on this work in an excellent manner for Milwaukee foundries. Just recently a fully equipped electric steel foundry, modern in every detail has been installed, and which is open to inspection by our visiting foundrymen. A completely equipped gray iron foundry has been in operation from its inception and has carried on in a very satisfactory manner whatever foundry training has been done prior to this intensive program.

This Scheme Provides Applicants.

It should be noted here that one of the very noticeable results already obtained by this part of the program is the general strengthening of the foundry apprenticeship idea among the eligible young men of Milwaukee. A full-time class of

foundry apprentices has given no little prestige to foundry apprenticeship. It is not uncommon that young men now request to be given an opportunity to learn the foundry business.

The Milwaukee apprenticeship program does not promote apprenticeship in the individual plant above that of any other. The district idea is stressed wherever possible.

District Apprentice Gatherings Fostered.

During the 1923-1924 season all Milwaukee apprentice gatherings were established as a regular part of the general apprenticeship propaganda activities. The last of these gatherings consisted of a dinner entertainment at which more than a thousand Milwaukee metal trades apprentices were present. It was strictly an apprentice evening during which the opportunity was taken to make the apprentices acquainted with the executive heads of our metal trades organizations. The parents of our apprentices were given an opportunity at these gatherings to become acquainted with the true idea and nature of this form of industrial education. It is apparent that not only they, but a goodly portion of the people of Milwaukee, have come again to realize the esential value of trade training. A few years ago it was impossible to convince anyone that a foundry apprenticeship was even so much as possible. It is not uncommon at present to have the mothers and fathers approach a plant requesting a foundry apprenticeship for their son.

District Program Had to Overcome Traditional Opposition

It was realized early in this apprenticeship work that the idea of apprenticeship had been almost lost to practically every class in society. This was particularly true of foundry apprenticeship. In order to re-establish this tradition of industrial training or apprenticeship it was thought well to enlist the support of the regular school system. Here, too, the industrial background had been almost obliterated. Pupils were supposed to pass directly from grade to high school, and thence on to college, neglecting the fact that more than 90 per cent of grade school pupils are shunted into industry before they reach high school.

Vocational Guidance Promoted.

A plan of vocational guidance through the efforts of the local metal trades has been established in Milwaukee's public and private school system. Instruction is given at the proper time and in the proper place regarding the major trades and professions in which people in this community seek their life work. The industrial background is thus re-established, not to the exclusion of any form of higher education, but merely to the end that the vast majority who never would or never could participate in higher education can be presented the opportunities of a systematic and well organized industrial education in Milwaukee's various trades and professions. Speakers representing these occupations are enlisted in this service. At regular intervals according to a definite schedule they present to these young people the manner in which people generally in this community make their livelihood.

Such vocational guidance scheme, while not intended to directly influence young people to enter upon definite trades or professions, serves to re-establish the link between the schools and industry which has for so long been broken. The tradition of apprenticeship is thus being gradually re-established in all classes and among all peoples.

A National Program Envisioned.

The Milwaukee idea envisions a national program of apprenticeship. It is hoped that in the course of time all industrial communities of this country will participate in their just portion of industrial training. Time and effort has been spent without limit to bring this message to other centers. The idea must first be established that apprenticeship, particularly foundry apprenticeship, is not only possible, but entirely practicable. Secondly, the idea must be born again that all industrial centers in America must provide such training activity as will make them self-sufficient in their skilled personnel. Milwaukee does not glory in being alone, or practically so, at the present time in this work. It could ill afford to do so if for no other reason than that it could not possibly train a sufficient

number of men, not only for its own use, but for many others as well. Milwaukee will only rejoice when all other American industrial communities have provided an adequate training program.

Foundry apprenticeship among American young men is possible. This statement is made only after actual results have been achieved. The detail methods including schedules of work, programs of study and the detailed mechanisms for carrying on apprenticeship work in the individual plant are on display and can be inspected by our visiting friends. There is nothing even to the slightest detail but what we are willing and anxious to lay before you. We are certain that apprenticeship is practical, economical and the only efficient means of training the skilled mechanics that are necessary. The number of regularly indentured foundry apprentices at work at the present time in Milwaukee foundries should be sufficient proof of this statement.

The day when every plant, foundries included, regardless of their size and character of work could train apprentices has passed forever. A district program alone will suffice. This presupposes a spirit of co-operation and a quality of frankness that will enable all organizations to co-operate in this most important work of training skilled foundrymen.

Milwaukee metal trade foundries have at present one hundred eleven regular foundry apprentices. They are competing this week for awards that have been set up by the American Foundrymen's Association. Their work will be on display at this convention. They can also be seen at work in the various Milwaukee foundries. Much still remains to be done. This is no claim for perfection. We are only removed five years from the beginning of this program. But we do claim first that foundry apprenticeship is not only a possibility but an actuality and second that only by means of a district program can a sufficient number of foundry mechanics be trained for an industrial district. What Milwaukee has done other districts likewise can do. Every possible and reasonable assistance will be given towards this fulfillment. It is hoped that the apprenticeship exhibit at this convention will assist our visiting friends in this important work.

The Employer's Expectation of Modern Apprenticeship

By R. J. Dory, Milwaukee.

Apprenticeship is not a universal panacea for all our industrial ills. While some misguided enthusiasts have made such claim the well informed and those who are making of apprenticeship a living reality in our industrial life today know that this is not and cannot be the case. Apprenticeship will effectually accomplish some very definite results and it will do much to pave the way for a solution of some of our most pressing industrial problems with which we are at present confronted.

A Supply of Competent Workers

Obviously one of the very first accomplishments of an actual apprenticeship program will be to provide an adequate supply of thoroughly competent and well-skilled mechanics. With the Milwaukee program of apprenticeship fully carried out, there will not only be sufficient number of foundry apprentices for any individual organization, but there will be, and this is far more important, a sufficient number of skilled foundrymen for the entire district. It is one thing to refer to an adequate apprenticeship in one organization and quite another to refer to an adequate apprenticeship for an entire district. This latter the Milwaukee program is accomplishing.

It follows very logically from this that if we have an adequate supply of skilled mechanics in this district that we will also have by this very fact an adequate supply of thoroughly trained men competent to fill the places in our organizations as they are made vacant. If apprenticeship is but another name for an industrial education, and this has been the object throughout in the Milwaukee program, young men will be reared in the foundry business who have been thoroughly trained in every aspect of modern foundry work. It only remains, then, in the course of a few years of journeymanship, during which the development of the individual will take place, to

note those who display executive ability. If the apprenticeship training has been adequate and sufficiently forceful to carry the individual on to further educational efforts, then there will never be at any time a lack of material from which executives can be selected.

Apprentice Training Provides Foremanship Material.

This does not mean that definite foremanship training may not be necessary. This does not mean also that the upgrading process must not be continued beyond the apprenticeship years. But it does mean that apprenticeship must become the foundation upon which an executive career must be built. We do not only expect here in Milwaukee this to be the case but we know full well from actual experience that this is one of the results of foundry apprenticeship. Young men who have been given a fundamental apprenticeship training are already in junior executive positions in some of our Milwaukee foundries. These are not expectations so much as realizations.

Apprenticeship should, however, provide the means of supplying an understudy for every important position in our foundry organization. And the day will come when it will be considered more foolhardy not to have understudies for every important executive position in our organizations than not to have adequate financial reserves. Apprenticeship alone can supply these understudies.

Apprenticeship Training Makes Organization Flexible.

Apprenticeship will make our organizations flexible. To have a group of young men in training in various departments of our foundries will make it possible to call upon our foundry organizations for unusual results under very trying circumstances. No sudden demand of production will find us unprepared. Young men in training become the mobile element in an organization. It is possible to shift apprentices temporarily from one department to another as the demand arises. While this would, if made general, invalidate the true educational aspects of apprenticeship, yet done only as an emergency measure, it becomes of value, not only to the employer, but to the apprentice as well.

A short period of work in a department where there is an immediate need for some skilled hands will in no measure affect the general results of the apprenticeship. In fact, if fully explained to the apprentice, a short period of emergency work in some other department will give an apprentice an insight into the trials and tribulations with which management is constantly afflicted. Nor is this a mere matter of theorizing. It has been proven in the actual operation of apprenticeship that such flexibility is one of the satisfying results of modern foundry apprenticeship.

Apprentice Training Should Promote Advancement.

It should never be necessary with an adequate training program to step outside an organization to fill any vacancy whatsoever. If men can be found outside an organization who are capable, then surely can men be found within the oragnization still more capable if they have had a thorough apprenticeship training. And yet we have become so accustomed to reaching out beyond our own organization for executive material that we scarcely realize the losses encountered during the period of adaptation when new material is being assimilated. Our industrial engineers have computed quite accurately the cost of replacing the man in the ranks. No one, however, has ever attempted to compute the cost of replacing a man in the organization. If understudies are supplied through an adequate apprenticeship program then no replacements are necessary. It becomes a mere matter of form to have the vacancy filled. And yet without an adequate apprenticeship system this is impossible.

The Milwaukee Program Not Limited to One Shop Training.

The Milwaukee program, as will be more fully explained in a subsequent paper, provides for the interchange of apprentices from one plant to another as necessity demands. Thus many young men during their apprenticeship become acquainted, not with one, but with several organizations. They have learned to adapt themselves, not only to different forms of organizations, but to the varying individualities within these groups. Their training as possible future executives has been thus greatly en-

larged. This, too, is a phase of the Milwaukee program that has even exceeded the fondest expectations of its enthusiasts.

A district apprenticeship program will provide an adequate supply of skilled mechanics. The district apprenticeship program by this means will, secondly, provide the material from which our organizations can be fully manned with thoroughly trained men. And finally a district apprenticeship program makes possible a flexibility in our industrial organization that has heretofore been undreamt of.

A District Program Reduces Labor Turnover.

If the district program of training is fully developed in any industrial center it must obviously affect to reduce the labor turnover. The object of the district plan is to provide not merely a sufficiency of mechanics for any individual plant but rather to provide for all the needs of the entire district. The co-operation between plants has this one objective in mind. The smaller organizations are enabled to do their proportionate share in the training of the mechanics necessary for the district. By this means the small plant can feel justified in employing the skilled mechanics necessary to carry on its work. No other means has yet been found to enable the smaller organization to do its proportionate share of this work.

All Plants in District Must Co-Operate.

Unless a district co-operate in this manner to carry on its apprenticeship activities comparatively few of the larger companies will be able and willing to promote a training program. All that remains then for the smaller company to do is to employ such skilled mechanics as they have need for and which, of course, have been trained in such companies sufficiently large to carry on a real and adequate apprenticeship program. Hence, it is that, even though the larger companies in our industrial communities do train apprentices the labor turnover will be quite large. The aggregate demand of the small plants will be sufficient to keep young men who have been trained moving from the larger companies to these smaller plants. Aside from the injustice of this arrangement, labor turnover is never effec-

tually diminished by the individual plant apprenticeship unless an entire district combines and co-operates in an adequate apprenticeship plan such as has been promoted here in Milwaukee, labor turnover will not be materially affected by apprenticeship training. The maintenance of an adequate supply of skilled mechanics for any industrial district is obviously a problem with which the entire district should be concerned. And unless it is the supply of skilled mechanics will never be adequate to the demands. Labor turnover would, therefore, be little affected.

Loyalty Promoted.

In addition to the obvious effects of a community program of training upon the problem of labor turnover, there is the added consideration that a man trained in an organization has many more reasons for remaining than for leaving. Loyalty is not a thing that can be grown over night in an employment office. And loyalty is at the bottom of this problem of labor turnover. Four years of training during the early years of manhood under the proper conditions and circumstances of work, wages and all around industrial justice will do more to build us a loyalty than any other one thing. And in proportion as the loyalty is increased will labor turnover be decreased. Apprenticeship, or real industrial education, is the necessary means to a loyalty which we are generally sadly in need of at the present day. And we need be little concerned with turnover once we have solved this problem of loyalty.

While on the surface it would appear that apprenticeship would affect only the supply of skilled mechanics, and hence, reduce the turnover only in this group in our organization, yet the fact remains, that if this portion of our personnel is a stable and loyal one, the other will be favorably influenced, and reflect the attitude of the former group. This is particularly true if apprenticeship is expanded to include an upgrading process generally among all the other members of our industrial organization. If each man is provided with an opportunity which is in proportion to his abitions he, too, will be a loyal employee. Thus in turn, if apprenticeship is considered as an industrial education open to all, our problem of loyalty will be in some

considerable measure solved. And this in turn provides the solution for the problem of labor turnover.

Apprentice Training Paves Way for Solution of Industrial Problems.

Apprenticeship cannot solve all of our industrial problems, but it can pave the way for such solution. If young men are not only trained to become skilled mechanics, but loyal members of an industrial group, some at least of our industrial troubles will begin to disappear. Obviously, such training to loyalty must be based on facts and be done with a sincerity of purpose as well as an openness of mind that cannot be questioned.

Moreover, apprenticeship cannot be made to cover up inadequate wages, poor working conditions or other fundamental defects in an economic organization. But if apprenticeship is not only made a means for training in manual skill and an education to a loyal and generous manhood, but an upgrading process for all employees, the way will be paved for the solution of any of our present industrial problems.

But an apprenticeship to do this must be a real and an educational one. It must be conceived along community lines in the broadest possible spirit of co-operation and frrankness. Its educational matter must not only be shop technique, but truth and justice and human understanding. With such an apprenticeship have we been grappling in the Milwaukee district. While we still have a long road ahead, our fondest expectations have been surpassed. In the hope that other industrial communities might profit by our experiences are we laying ourselves open during this convention to a complete examination of our apprenticeship activities. Our further expectations for apprenticeship results are based not upon theory but upon the satisfactory results that we have had up to the present.

The Part of the Vocational School in Industrial Training

By R. L. Cooley, Director Milwaukee Vocational School

I knew nothing of the type of discussions or papers which would precede me upon the program, but I have had these ideas for many years. I have been sort of a lone voice crying in the wilderness on the subject of apprenticeship, so that I have become quite accustomed to occupying the whole program on that subject. Things are changed now, and the splendid papers and discussions that have preceded show me what a mistake I should have made had I intended to cover the whole field.

I read recently that in the excavation over in the East where they are finding out about the civilization of thousands of years ago, they discovered a cuneiform inscription, and had it deciphered. When deciphered it was found to be a lamentation on the part of the writer that the world had gone to the devil and that boys were no good any more. Now, that was antedating Jesus Christ. I don't know but what it antedated Moses, so if any of you people are inclined to say boys are no good now, don't think you are saying anything new.

I am here to tell you, you have the best generation of boys, that all of the advantages of civilization and all of the advantages of all of the nations on earth can give you. If you don't like it just turn your eyes inward. If boys then were as bad as this fellow thinks they were, think what a specimen you must have been. Now, I think we can dispose of that.

I am going to touch briefly upon just a few points. In the first place, do you need just trained animals or do you need trained human beings? If you need trained human beings, how are you going to get them? I know only two ways. If you invent a third way I wish you would name it, because I have sought and searched in vain for a third way.

One way is to set up a course of training in a school covering the continuous period of time, get your boys, take them

in, keep them there through that period of time continuously, a period of three or four years, and then turn them out. That is the straight school method pure and simple.

The other way is to get out on the job and learn while you earn. I know of no other methods. Do you? Can you suggest any other method?

Let us turn our attention to the trade school method for a moment. The first thing that anybody thinks about is a trade school, particularly if they have been a little bit annoyed by the demand or request upon the part of people supposed to be earning, that a part of their time be given to learning, especially if this learning demands that they go outside of the plant or to go to some department in the plant.

They say, "Well, apprenticeship doesn't pay." Well, colts do not pay. Suppose you were iterating and reiterating, "We must have horses, we need them in our business." We must have horses, but colts don't pay. Suppose you neglect the ordinary processes of breeding, then by and by you try to make more horses by paying more for a horse. That is a great breeding process, isn't it? You would get a long ways on that basis, wouldn't you? Well, now, the fellow that says, "apprenticeship does not pay, but we must have the right kind of men," is just like the fellow I mentioned a moment ago in this matter of horses.

We have had a trade school in this city for nearly twenty years, and it is a good one, it is a fine thing, but as an adequate training agency I do not believe trade schools have yielded results. Why? When the young fellows come up and get ready to go out into employment, as soon as the restrictions of the law permit, you have three types of fellows. You have those whose dads are economically so fixed they can send them to high school, and who want to go to high school. You have those whose dads are sufficiently well fixed economically so they can send them to high school, but the boys don't want to go to high school, so they choose the trade school. Then you have the fellows who have to go to work, and they go out and earn while they are learning the process, getting a job somewhere.

Now, as to the fellows that go to the trade school, they do

well, for by the very process of economic selection which restricts them to those whose parents are able to support them during this period of school, you get the type of fellow who does not function by that other process of natural selection.

What do they do when they start to trade school? "By Jingo," some one says, "we need patternmakers," and every fellow starts in making mallets and things of that kind. Or else it is wood work, or the machinist's trade or something similar, and you fill your schools up with a lot of fellows who do not afterwards function in that trade, and if they did, their total number would be hopelessly inadequate to meet its demands. The figures throughout the United States show that in proportion to the countrywide need for workers trained in the various trades, the trade schools have turned out a wholly insufficient number of men. Furthermore, the number of trades for which training is given, is very limited, and even in these, the trade school men are so few that they are only a drop in the bucket. So, gentlemen, I say all real results that have ever come, have come from learning on the job, except in a very few instances.

The people who come from the older country, those who have not been trained here, say our American boys are no good, that they will not work in a foundry, nor anywhere else. As a matter of fact, it's a lie that the boys all go to high school and are all looking for white collar jobs. Let me tell you, we have about 4,000 boys, to say nothing about the girls, going to high school in the city of Milwaukee. They are to feed the professions. They are to feed the commercial jobs, the type of jobs that profit by high school education, but out in the trade we have 14,000 Milwaukee boys.

We do not have too many boys in the high schools, but we haven't been doing the right kind of thing for those boys who did go out and offer themselves for service. Now, gentlemen, the learn-while-you-earn process is the only hope, and the only rational and reasonable thing to do is to put some system and order and administration into the education of our young people, into the places of work, in your shops and stores.

We have to recognize the fact that this period between the

ages of fourteen and twenty, when these boys are yet clay in your hands and may be molded, has to be an educational period.

We must no longer offer boys just jobs, and we must no longer offer boys in great numbers just jobs, because they are the only purchasers of your materials. We have to recognize that if boys cannot be made to serve, to earn, to buy, and to support families, you might just as well let the wheels stop turning in your factories, because when all is said and done, foreign trade is a minor thing and profitable only on a basis of a domestic situation that makes business in a domestic way profitable.

We must build up on a sound basis, remembering that nothing on earth except the human being ever buys anything. Did you ever think of that? The great masses of boys going out, by their earnings and ability to spend, determine your market. Five hundred primitive Indians or primitive undeveloped people give you no market. Five hundred well developed families supporting honorable citizens will make you a tremendous market. If we could afford just once to do for one generation of our boys as they go out, the things that might be done, there would be such an impetus to business that it would more than equal the discovery of a new continent of uncivilized people.

We have, therefore, a greater interest than apprentices only; we have a greater interest than merely training them for efficiency in their operation; we have an interest in all of the apprentices, in all lines. We have an interest in all boys and young people as they come up, if we are intelligent and not shortsighted. There is no such thing as individual prosperity. We might just as well run a pipe line out onto Lake Michigan, blow up a bubble and say, "Ah, we have created something new," and just as soon as we turned around it would be gone.

Gentlemen, I am tremendously interested, and I shall do everything I can to co-operate with your splendid efforts, for we have received splendid co-operation in your line. I happen to be in the position where I am just as much interested in other apprenticeships as I have been in your trade, and while you say it is your especial responsibility in this line, your civic

and intelligent business interests cannot limit your responsibilities to just your own part here.

Last week we had 10,200 employed young boys and girls coming to our school, coming on part time in this city. This makes our vocational school the neck of the bottle, for we get all of the boys and girls who leave school early and go out to work, and while we want to co-operate in every way we possibly can with you in the things that you see in a technical way are essential, we think we also see certain other things. These are, that in the development of these boys and girls during this period, we must recognize the fact that people cannot order a state of mind, nor can they order attitudes and tendencies in people when they just seem to think that those attitudes and tendencies are needed for immediate purpose. If the young people come up under the wrong sort of influences, they are going to go wrong thereafter in their tendencies, and those wrong attitudes and tendencies are the things which will make it impossible—difficult, if not impossible—for even right-minded people in either group in this great industrial warfare to make reason and common sense and the better thoughts of life prevail in the situation.

A great many young people come to us who do not know what they are going to do, they don't know what they ought to do. We are a great guide while working in this institution. We are promoting the idea of their making the next three or four years of their life a training period to fit themselves into some niche. We often hear the talk of this being a great age of specialization, but that apprenticeship is an impossibility. Gentlemen, it is not. All we want for every boy and girl is what you want for your own boy and girl, a plan of life.

You cannot plan a life upon a basis prepared to do only one thing. It will topple over. It won't stand. A little broader education is the only thing upon which a specialization can safely be built. You get neither the right disposition, right attitude, nor anything else. We are establishing apprenticeships in connection with the shoe factories and various other institutions here. There is nothing in the situation that prevents a young person's life being planned. Just as soon as it is

planned, with the employer and the school, co-operating on that plan, we have the essence of an apprenticeship, whether it be in connection with a grocery store or a foundry.

Well, gentlemen, did you ever think of it, we are all in the same business churches are in; especially you people in the steel business. Heat and baptism. Did you ever think of what the churches do? They raise people who have fallen, then they baptize them, and then they come out presumably with character. That is just what you do in the heat treating business. Take a piece of iron, cut it off, put it into the furnace, take it through a certain emotional experience. There is nothing that I know of which so compares with emotion in the spiritual world as heat in the physical. After you take the steel through a certain emotional experience, you plunge it, baptize it, and it has character. After you have given it that character, it can be fitted into the positions where it has to keep its age, where it has to stand the strain and stress.

I tell you, as we get this great mass of young people coming out, we have to bear in mind that among these other things we do, we have to put them through certain experiences. We are in the heat treating business, and that is a phase of the work which cannot be neglected. It is a phase of the work that perhaps the schools can aid in doing. It is not only upon the technical side that we can assist, we can assist upon this other side.

The time has gone by when a man can spit tobacco juice on his shirt front in order to be a fit man to work in your institution. Laboring men can be gentlemen, and I hope that one of the things that will come out of this apprenticeship situation is a little recognition of the fact that during this period when boys so tend just to be rather conceited, during that bumptious period that comes in between fourteen and twenty, some attention can be paid to that phase of the work.

I should be very glad if during the time you are here, if you could get up early enough in the morning, you would come over to the school about eight o'clock and see that great mass of young people in the assembly. I think you will see that a great deal can be done by just a part-time contact during the

period of apprenticeship or during the period of employment, even if it be in an apprenticeship.

I also wish to call your attention to the fact that because these part-time schools are coming all over the country they need the support of just such men as you. Then, also, if the young fellow has to go out without a plan, just a casual worker without anybody paying any attention to him, he needs this part-time contact with the school far more than he would need it under a splendid system of apprenticeship, that might be gotten up by you, gentlemen, in your own lines of business.

You see, I could not help giving a little propaganda for our part-time school in my talk here this morning, and I think that what I have said is sufficient to show what we are attempting to do.

Why a Graduate Apprentice Talks Apprenticeship

By C. J. Freund, Milwaukee.

It is my habit to be quite enthusiastic over apprentice training whenever I discuss this matter. Sometimes I am talking to a boy who wishes to take a regular job and does not believe in apprentice training, sometimes I am merely explaining the system to one who is already convinced that apprenticeship is the only way to learn a trade properly and very often, outside of working hours, I am telling some layman about the apprenticeship system. In every case I am an enthusiast and it seems to me, no matter how extravagant my language, that I am not doing the subject justice. This enthusiasm is due not merely to the fact that I am engaged in apprentice work but more especially to my firm personal conviction that apprenticeship is the only correct method of industrial training.

I could give you very many more or less theoretical reasons for this conviction but there is a more striking cause than any of these. When a man is talking about something, people will usually wish to know whether or not he has had any first-hand information, whether he has had any experience with the subject. My experience with apprenticeship has been very satisfactory, so much so that I feel a certain gratitude toward the system, if gratitude toward an abstract thing is possible. I started out quite a few years ago to learn something about shop work during my school vacations. In my home town, I was given work in a small foundry and machine shop by the president of the corporation who owned the shop. This gentleman was very gracious and very much in accord with the idea of learning by practical experience. He was very anxious to assist me but he had not had much experience with formal apprenticeship and all he did was to introduce me to his general foreman with instructions to "break him in." But that foreman had much different ideas. He had no use for boys and the result was that

I was put to work at one machine, an old tumble-down contrivance for boring and facing pipe flanges. When I left that machine it was to run errands or to rake up leaves, wash windows and wheel black dirt at the home of one of the officers of the corporation. Every question that I asked regarding my work was answered with a sneer or a snarl. Inasmuch as my primary purpose in working was to learn, the situation was anything but satisfactory. I was finally fired for lifting a wheel with too light a chain. I tried other shops. In all of them I was admitted to audience with more or less important officials who maintained that they believed in learning by experience and emphasized the importance of being changed from one operation to another. And all of them gave me work on a machine or core bench and gave me no further thought.

Organized Training vs. Haphazard Training.

After spending six years of alternate attendance at school and attempts in this haphazard fashion to gain shop experience I was finally directed to a shop where there was established a regular apprenticeship system in charge of an organization of supervisors and instructors and the difference was like a flock of big orders after nine months of acute business depression. I found people who would answer my questions, I found foremen who gave me real instruction, I was changed from one operation to another without even having to ask for it. I began to make progress, I was satisfied that I was gaining experience under the proper conditions.

I firmly believe in apprenticeship because I realize that what little I know about industrial matters I could have learned in no other way than by apprentice training. Before I had an apprenticeship I learned nothing. That is one good reason. There are others.

Organization Keynote of Modern Industry.

Modern life and modern industry especially, are distinguished by many things. One of these is organization. Everything has system and although the system is sometimes overdone,

the results have been very beneficial. People with similar tastes and interests have their organizations for mutual benefit and enjoyment. Grocery men and shoe men and milk men have organizations to promote trade and standardize methods; fruit growers and cotton growers and wheat growers have organized to market their products. Merchants have association to promote business, manufacturers have associations for research and protection. Within the plants we find operations organized and production has reached unheard of figures, sales departments have been better organized and customers are reached that were never thought of before, everywhere we find everybody organized. It has to be. If all the people in this room, without planning or arranging, were simply to go to work, pell-mell, to build a ship, for instance, we would not get very far. It would be necessary to place some one in charge of the work and to give every man some particular task. In other words we would have to organize. Nothing can be accomplished, even by one person alone, without organization.

There is probably no activity in American life which is so highly organized as education. We have an educational system which permits everyone to attend school and the organization of the American college and university is truly marvelous. The schools may have their faults but lack of system is not one of them. Young John Jones enters high school. Very likely he has been playing fast and loose at home in the typical American manner. He is now confronted with systematic registration, systematic courses, systematic instruction. It irks him at first but long before he has reached his senior year he has grown to like it, he becomes used to thorough planning and arrangement. Throughout his high school course he finds things quite definitely known and established, he knows what will happen and when.

Organization of Experience Necessary.

Young John Jones graduates from high school and goes to look for a job. He wishes to learn the wholesale grocery business, let us say. Does he find things organized and established? Very likely not. He is told that he can get into the business and work his way up. After that he is left very emphatically to

himself. If he pulls through and makes a success, well and good. If not, well and good, too. There is in his entire situation an absence of certainty which is very discouraging and frequently completely destroys whatever interest he may have had in the business. Nor is the grocery business any different in this respect from most others.

This is another great plea for talking apprenticeship. There are two great elements that make up a man's professional or trade equipment. They are schooling and experience. We have thoroughly organized the school training. Why not organize the experience? Apprenticeship is merely organized experience. We hear so much talk regarding the necessity of gaining experience. When our young friend John Jones was hired he probably found himself seated at a table opposite an impressive looking man with shell-rimmed spectacles. The impressive looking man will probably tell him that he will need to have some years of experience before he can hold a real position. That is true. But why should not the experience be laid out and organized for him so that he may know what is before him and what is required of him? Why should he not have some assurance that he will work in the coffee department and the canned goods department and every other department of that grocery business? Why should he not have foremen and instructors who recognize in him a young man who is there to learn and show him what he should know? Why should he not be made to feel that the company for which he is working is willing to help him out of his difficulties, of which he will have plenty? You know as well as you know that you are assembled here that every human effort must be organized to be successful. Why, then, are young men still expected to be successful in gaining experience without organization of any kind? Why, then, in other words, are they not given apprentice courses?

I talk apprenticeship for the boys' own good. When a young man comes into our office, he is to me not merely looking for employment. He is a young man just beginning his career, he has ideals and ambitions. He is eager to be successful and to count for something among his fellow men. I have an interest in him as a young man who is standing in that all important but extremely uncertain place in which I was standing but

a very few, very short years ago. I know how he feels. This young man, by the very act of his coming to us to discuss this matter and ask us for work, has expressed his confidence in us and we dare not violate that confidence.

Failures Largely Due to Lack of Early Training

I am old enough to have had the opportunity to watch practically the entire career of certain men who are now in middle age. I just barely remember their starting out fresh from school, or high school or college, full of ambition and enthusiasm, willing to take any kind of work and two men's share of it, confident that in a very few years they would be well advanced and comfortably fixed financially. I have noticed the cheerful patience with which they worked through the first five years of a blind alley job without much improvement in their condition nor much loss of optimism. They were getting experience. It would take a little time. I have seen them reach the point where they have completely mastered the work they were doing without having the opportunity to learn any other phase of their business. I have seen their first dread suspicion and later horrible realization that they were in danger of becoming failures. I have seen the gradual loss of their fire and strength with increasing age. I have watched them lose interest in their work, and succumb to the routine of their job. I see them now, working at a desk or table, with spectacles, eye shade and a pencil on their ear, careless about the appearance of their threadbare clothes, thin and bent without a hope for the future and still they are less than fifty years old. I have studied these men with the best of my ability. I have discussed their cases with friends of theirs and of mine who have been successful and the result is that I am convinced that the principal reason why they have not made progress is that the experience of their first few years was too limited and their position did not, in the regular course of things, lead to a better one. They never had the opportunity to serve an apprenticeship. I think of these men as I survey the eager, sometimes nervous youth on the other side of my table. I tell him all this, but in different words. I show how an apprentice training course gives him the right start. I explain to him how an apprenticeship will take him into every

division of the trade which he is contemplating so that his experience will not be limited. I show how acquaintance with all these divisions of the work will enable him to make an intelligent choice of a specialty and enable him to be more efficient in that specialty.

Adequate Apprentice Training Worth While

Of course, not every boy who serves an apprenticeship will advance rapidly, some have not the ability, but certainly an apprenticeship is the surest way to advance for one who has ability and in any case, every boy is better off with an apprenticeship than without one. I tell the boy all this because I have an interest in him and I wish to help him as much as I can.

Shop Work in Disrepute. Why?

I talk apprenticeship because I believe that apprenticeship universally established will solve many of the industrial problems which confront the world to-day. Certain it is that any trade or calling which involves the least little bit of manual work has fallen into disrepute with the American people, and the result is that there is a great scarcity of workers in almost all trades. It is not necessary to announce this fact in this assembly. Only yesterday afternoon I overheard two members of this Association discussing this matter and one of them said that he would give fifty dollars merely to look at one really good, steady, all-around molder, even if he could not hire him. This may be a little exaggerated, but it expresses the condition which exists in all trades. Visit the graded and high schools of any city and ask the students what they wish to make their life's work. They hope to become physicians, engineers, advertising men, salesmen, dentists, merchants, anything and everything which does not mean a little physical labor. Few American boys ever choose to become artisans. Those who do become mechanics are forced to it by circumstances. The reason for this is not that the trades are not well paid. Stevedores, glassblowers, plasterers, all receive excellent pay and still there is no mad rush to enter these callings. The difficulty is that the trades have lost their dignity. Mrs. Bingbing, however poor she may be, insists that her Alphonse must become a professional man. Her neighbor's son became a lawyer and nothing less will do for her boy. She

and Mr. Bingbing had to work very hard to make a bare living and her son shall not spend his whole life laboring. She will be disgraced forever if he fails to be anything more than a mere toolmaker. Certainly it requires as high a class of man mentally to be a first-class molder as it requires to be a first-class bookkeeper and it certainly requires a higher type of man in every posible respect to be a smelter foreman than it requires to be a chief clerk or secretary. Why, then, cannot the trade have an equal dignity and standing in the community? We believe that this dignity and standing will be restored by apprenticeship.

Organized Apprenticeship to Play Part in Industry.

In the first place, apprenticeship will show the people that training and education are required to enter the trades as well as the professions. An apprenticeship is a method of education, and when it once becomes generally known that a boy must pass through a formal, recognized period of training before he becomes a mechanic, the trades will have a greater appeal. Whenever a price is attached to something a demand is created. I well remember a certain educational institution where a small group of students were very enthusiastic about debating and they tried in every way possible to arouse interest in the student body in that activity. Debating teams were brought from far-distant institutions for competition and admission to these debates was free. Still never more than a mere handful of students were present. Then some one happily conceived the plan of charging admission. Fifty cents were then taken from every one at the door of the debating hall which from that time on could not accommodate the crowds. Apprenticeship will have the same result. It is the price of admission to a trade and it will draw the crowd.

I talk apprenticeship because my own experiences with apprentice training have been very profitable and pleasant, because industrial training must be organized as well as every other industrial activity. I talk apprenticeship for the boys' own good, because I believe apprenticeship will restore to the trades their proper dignity and last but not least I talk apprenticeship because it is part of my job.

Apprenticeship From an Apprentice's Viewpoint

By J. Edwards, Milwaukee.

As an introduction to this subject, I will give a brief outline of the history or development of apprenticeship. The apprenticeship system of industrial training seems to have originated far back in the Middle Ages. There is abundant evidence that it was already fully established in Europe as a recognized system of training for all skilled trades, as far back as the thirteenth century. In the sixteenth century it became legalized, having been previously maintained by guild system supported by municipal authority. A law was passed that a uniform term of seven years' apprenticeship must be served as a training period precedent to the right to practice any manual trade. The old apprenticeship system was calculated to produce a type of workman who was thoroughly master of his trade, through intimate contact with his employer or master, due to the fact that the apprentice usually lived with him while serving his apprenticeship. This system was based on the principle that the apprentice was first and foremost a student rather than a wage earner, in fact, in some trades an annual premium had to be paid by the boy's parents for each year of his apprenticeship training.

Introduction of Factory System Changed Need

Since the introduction of large factories and shops, the old system had been impossible and until recent years apprenticeship was only recognized in the attitude that a man had served his time. Ask almost any mechanic, and he will tell you that he served his time with such and such a firm or at such and such a shop. Question him further and he will probably say that he commenced by doing odd jobs and only learning the trade by contact with it and his own ability to learn by observation.

So the apprenticeship system has been revived in recent years and has been greatly modified to meet the altered social and

industrial conditions. These modifications include: a maximum period of four years; a raising of the age at which an apprentice may commence his course, the institution of a probationary period before the actual signing of the contract; a substantial increase in the scale of wages payable during the apprenticeship and a course of technical education to be maintained during the term of apprenticeship.

A General Understanding of Apprenticeship Necessary

This shows the comparison between the present apprentice and apprenticeship system and that of a century ago. Doubtless there are many people who know of the apprenticeship system of olden days, but who would have no idea of how it has been revived, especially in this country, and of the great changes that have been made. At present there is little information, outside of articles published in a few technical magazines, that is available to the public, and as many firms are adopting this system, some method ought to be taken to let the general public know more about apprenticeship.

When I first applied for a position in the drafting room, I had no idea of the apprenticeship system. I was told that it would first be necessary to put in about one year of shop work, commencing with the foundry. The foundry appeared to be a very dirty and undesirable place to work in and for the first few weeks I had no desire to stay there. However, one day the superintendent of apprentices called me into his office and explained to me what the apprenticeship system was and the opportunities presented by it. He also outlined a contract or a schedule of work for me, requiring three years' work in the foundry, and I realized the amount of thought and consideration given to an apprentice in drawing up his contract. The contract was made so flexible that if the necessity developed for further training or a change in a schedule of work, it could be taken care of with the approval of the apprentice board. This is a good feature, as during an apprentice's period of three or four years, conditions may arise which call for additional training and if he were subject to a fixed contract he would be unable to take advantage of such conditions.

General Information Which Should Be Given

The idea of apprenticeship is to give a thorough training in the fundamental practices of one's trade, and when this is obtained, one can specialize in any particular branch of that trade. In making a product one should know what happens to it after being completed, and so, in the case of steel, an apprentice desiring to become a steel melter should have a certain length of time in his apprenticeship allotted to the foundry. He should do actual molding and thereby learn what happens to the steel after it leaves the furnace. He will learn of the difficulties encountered when the heat is too hot or too cold and various other problems. Again, an apprentice who wishes to become a pattern maker should have some foundry experience and by that I mean actual molding and core-making. I have seen many patterns which have been designed with very little thought as to how they were to be molded, this being due probably to the fact that the pattern maker had very little knowledge of what happened to the pattern in the foundry although he may have been a first class woodworker. This idea is carried out in the plant of The Falk Corporation. An apprentice who is specilizing in a certain line of work pertaining to the trade, receives the necessary experience which will prove of the most benefit to him.

How Apprentices Are Grouped

The apprentices are divided into groups based upon the previous education received. There is not much distinction made as to the actual shop work done by each group which shows that no matter what education the apprentice has received, the only way to learn a trade or profession is to start at the bottom. Of course education is a great advantage, an educated person having more ability to learn, but to take an apprentice course requires the ability to become skillful and the will to work hard, which depend on the character of the apprentice more than on the degree of his education.

Theoretical Training

An apprentice should receive some theoretical training along with his practical work. The law requires that an apprentice

should have a minimum period of four hours per week for study. The majority of the apprentices at the plant are sent to the Milwaukee Vocational School where they are taught the theory of their trade by experienced instructors. This arrangement undoubtedly gives better results than a class or study period held at the plant. An apprentice who realizes the value of an education will know that a period of four hours per week is not enough in which to study the theory of his trade and to achieve more he will have to do further studying in his own time. Arrangements have been made with a correspondence school to allow apprentices to obtain courses at a special rate and courses have also been outlined for those who wish to attend night school. I took advantage of both, using the study period allowed at the plant to prepare my lessons for the correspondence course. There is no doubt that the idea of working the practical and theoretical side is the ideal way and every effort is made to provide the apprentice with appropriate study work.

Competition Needed.

The spirit of competition should be present in any apprentice system. At The Falk Corporation a monthly report is made on the workmanship, progress at school, conduct, punctuality and attendance of every apprentice. The results are posted showing the standing of each apprentice in each respective group and the report is sent to the parents. This method provides a detailed account of the progress made by the apprentice and also produces an element of competition throughout the entire system. The culmination of this report system is the presentation of awards to those who have shown the most progress or, in other words, those who have attained a high average in monthly ratings.

Workmanship is rated highest, which I think is only logical, as an apprentice who makes less progress in school, but shows a good degree of skill and effort deserves more credit than one who is excellent in school, but does not produce such good results in the shop.

Discipline Necessary

The necessary discipline under which we work develops the necessity for punctuality and attendance, respect for our employers, willingness, cooperation, and honesty in what we do and say. All this develops character, and any firm maintaining an apprentice system, having in mind that they are handling the material for future executives and so forth, as well as skilled workers, should enforce strict discipline.

Cooperation of All Factors

To make an apprentice system a success, demands the cooperation of all the executives and foremen employed in the plant. They should be thoroughly in favor of the idea and should be willing to give personal attention when necessary. At the plant of The Falk Corporation this spirit is dominant and all the foremen are boosters of apprenticeship. They are willing to assist us in any difficulty and are always ready to answer any question. We have been told never to hesitate to ask any questions we have in mind pertaining to our work. I remember one time I asked the foundry superintendent some information regarding a casting and in the conversation which ensued he said, "Never fail to ask a question or obtain information you may require from a foreman or other superior. Now is the time to discuss your work because when you go out to work for yourself you will not be able to do so as freely as you can while an apprentice." Any apprentice who desires information about the work he is engaged in, and of that being done in other departments, shows that his mind is active and that he is thinking about what he is doing, not merely putting in a certain number of hours' work per day like the average employee. This attitude might be summarized in a slogan, "Think while you work," and it would be wise for every apprentice to adopt it.

Apprentices Should Cooperate

The apprentices, who are assisted in every way by the foremen, should retaliate by endeavoring to cooperate with the foremen as much as possible. Of course, this attitude can be

overdone and a little diplomacy should be used, bearing in mind that a foreman has other employees to attend to and the fact that being responsible for a number of apprentices means additional work.

The term of apprenticeship is a period of education, and when we consider the fact that we are paid employees it is only justifiable that we endeavor to accomplish the most we can and to give our employers the best we are capable of. As I have mentioned before, in the old apprentice system the apprentice was primarily a student, and therefore received little compensation for his work. Now that we are learning our trades in a manner vastly superior and are receiving adequate compensation, I think that every apprentice should realize that to maintain the standard of apprenticeship and to produce the results which the employer expects to obtain from an apprentice system is dependent on him and his attitude toward apprenticeship. There is no doubt that one could go elsewhere and obtain more money than is paid to an apprentice but he would only be receiving remuneration for his services and in comparison would not be as well off as an apprentice who is receiving an education as well.

Discussion—Apprentice Training

L. A. HARTLEY: What I think of apprenticeship has been largely influenced, of course, by my recent visit to Milwaukee. It is an outstanding piece of work that is being done here, as nearly as I can see, from the brief time I have had an opportunity. Wisconsin authorities are covering the subject very thoroughly.

The need, it seems to me, is the thing to stress, and perhaps I might just briefly and in a few minutes indicate to you what seems to be the outstanding reasons for us being interested. I want to call your attention to the fact that our consular service is our marketing agency in the markets of the world, and when Europe becomes rehabilitated and gets back on its feet we will find ourselves in competition in the world's market, with young, red-blooded salesmen from the production centers of Europe, who will have no interference whatever from gold lace and dignity that they formerly contended with.

There is a question we might ask ourselves; when Europe is rebuilding, putting bath tubs in their homes, in their hotels and putting in heating plants, making a modern Europe, copied somewhat after America, will they reproduce a flour mill such as the Pillsbury Milling Company in Minneapolis near the market, or will they buy in Minneapolis? Where will they get their steel, in Pittsburgh or will they get it close at hand? If they do, we will have to get right down and get busy.

We are now in a time of restricted immigration. We have in the past received most all of our skilled labor from Europe. Usually we have had the first generation on the Atlantic seaboard and the second generation out here. Restricted immigration will be a policy of this country for ten years; I don't care what you say about this, for no great national issue that has been decided by general consent of the United States Congress has ever been changed in less than a decade.

All other things being equal, the quality of product will determine the amount of your sale, and you have the handicap of the old country to contend with. America produces more than fifty per cent of the basic raw materials of the world. We can either throw ourselves back upon ourselves and begin to produce as we formerly have produced the raw materials of the world, shipping them to Europe to be manufactured and sent all over the world, or else we can produce skill in this country which will enable us to produce quality goods and go on the market and compete with European products.

We must develop apprenticeship. If we do not develop apprenticeship, it means for us nothing more or less than for us to become one of the second-rate powers, so far as manufacture is concerned.

We must do it. It is not a question as to whether or not we have a choice in the matter, it is a question of absolute necessity, as I see it. We must get down to brass tacks and do this work. I am proud to be associated with a group of men who are thinking this question over seriously.

DR. R. MOLDENKE: I would like to, before it is forgotten, go back to the original remarks of Mr. Hartley. He said that, with the association of trained mechanics on the other side, the output over there was going to be used to bring up their products in competition with us over here. That point was interesting to me, inasmuch as the immigration laws, as he stated, were going to keep out the skilled men for at least ten years to come and that we would have to look to our supply of trained men. When I was over there September a year ago, I was the guest of not only the French foundrymen, but also the German foundrymen, and in both cases I found they were devoting tremendous attention to the training of apprentices and in turning out promoters. In Paris they had a very large exhibit at their meeting, which was under government auspices and not under the auspices of the foundrymen proper. In Germany, however, the exhibits, which occupied about one-third of the entire exhibits of the convention, were educational, and were the direct outcome of the work of the foundrymen and industrial people generally, backed by the government to some extent. There was room after room filled with drawings, pictures, patterns, castings, wooden models and methods of working, and so forth. These exhibits were visited by groups of apprentices, boys with little caps on their heads and in knee pants. This, to my mind, shows how the problem of educating the young man is taken hold of intensively over there. Since the young men trained in Germany will have a very leading part in the reparations situation of the future, and due to our immigration laws will not be able to come to this country, it behooves us very particularly to see that we are prepared to meet the industrial competition which is sure to come.

A. E. MCCLINTOCK: As one looking into the Milwaukee apprentice plant from the outside, there have been three things that impressed me. The first is the high type of boys taking up foundry work, and second, has been the definite and systematic course of training offered the boy, and third, the fact that the inducement is not the inducement of pay, but an inducement of an education. Pay is not stressed, it is secondary. The boy takes up the work because it gives him an opportunity for an industrial education. Foundrymen, generally, in my experience, have been trying to induce boys to take up the molding trade by offering them more money and then not having any systematic course of training.

A MEMBER: There is one phase of this problem that has not been

touched upon that I would like to get some information on. My place of business is in Chicago and I live in one of the small suburbs. We have in our suburb a good many young boys. Now, it is not practical, as I see it, to introduce vocational training in suburban schools. I would like to get a little light on that. I would also like to get some information on how Mr. Cooley goes about it, if he does, to influence the students in our shop. We don't call them apprentices; we call them student mechanics. I would like to know if there is a definite plan here in Milwaukee in influencing your students towards particular trades. Now, take it in the foundry end of it; we have our foundry needs, we need foundry apprentices or students. Other lines need students or apprentices in their lines. How are the public schools going to meet that need in a small community? It is all right coming from a locality where they have four or five towns in close juxtaposition to one another, but how in a little town the size of my town of Elmhurst, Ill., that has eight thousand people?

R. L. Cooley: Perhaps it would interest you to know there are fifty-two schools like our schools in the state of Wisconsin. We have fifty-two cities of over eight thousand people in the state of Wisconsin. It is not difficult. The gentleman just stated the rather hopeless fact a community of eight thousand can't do thus and so. When people really begin to study the thing and see what they can do, they find they can do a great many things they didn't know they could do.

We have had the belief ground into us that if there are two or three or four hundred boys whose parents are able to send them to high school, able to keep them in idleness and send them to high school, then the community can afford to build a building and hire professors and all sorts of things to take care of four hundred fellows that are fairly well cared for already from the economic standpoint. If, however, you have five hundred fellows, that are of the same identical age, out working in the community in various lines, earning three or four hundred thousand dollars a year, there has been an assumption that the community really can't afford to do anything for those people.

Isn't it odd that if several hundred people in the community go to work, the community says, "Well, we can't afford to plan any part-time education or spend any money on them," but if you have three or four hundred idle youths of well-to-do families they can lavish all kinds of money on their education? Now, you just get that over in your community.

Get your community to realize that the proposition of taking care of young people who have gone out early in life to work, still in the plastic stage, still in the period where they can be educated and influenced and something done for them, that they would not bankrupt the community at all by spending perhaps, as Milwaukee has authorized to be spent, or is authorizing to be spent, a million and a half dollars

on the assessed valuation of the city. This is financed in such a way that we do not have to take it away from the kindergartens or fifth grades, or anything of that kind. Here we have set aside in over fifty cities in the state of Wisconsin a margin of a million and a half on the assessed valuation of property to go to the education of the young people who at the age of fourteen up to nineteen years go out to work. We have fifty-two cities that are doing that.

Now you have a similar law in Illinois. Do you know it? Well, you have. The only difficulty in Illinois, you did not set your money aside. There is not a proportional budget set up whereby the state has said a certain amount of money will be available for this purpose. You have made everybody grab out of the same grab-bag, so that Chicago now has a tremendous problem right with this condition, as you are having all over the state of Illinois. In our state we made it a separate problem. We said the education of boys and girls who have gone out and worked is a distinct problem and they should have a distinct education and money made available for it.

A MEMBER: The second part of my question was: "How were they influenced toward the trade?"

R. L. COOLEY: Very briefly I can state, I think, in not more than two minutes. In the first place, our vocational school is the neck of the bottle. Every boy that goes to work between the ages of fourteen and eighteen is required to spend one day out of each week in our institution. When the boy comes out and has his job we say, "It is all right, you have your job; how are you going to make your living when you are a man?" His answer is invariably, as he looks down, "I don't know." "Well, you are going to be a man, aren't you?" "Why, sure." "Then that is fixed, you are going to be a man some day. Well, now, when you get to be a man you want to live like other people; you want to have a family bye and bye. Of course, you don't think much about that now. Now, about how much is it going to take to raise a family?" They are always very low in their estimates, but it gives them a thought. Then we say, "Now, how are you going to earn that much money? Somebody going to give it to you? What do you think of a farmer who goes to market with an empty wagon? If you went right out now to work, what have you got to sell?" You have to start boys thinking.

Then we have in our institution a great variety of things. We have watchmaking and shoemaking, and I could enumerate many other branches of industry. Sometimes a boy says, "I am going into the shoe factory." "Well, do you think you would like to continue?" "Yes." "Good, we need shoemakers and people in the shoe business, and, son, you are going to stick. Now, we want to help you." They come to us in that loose way, and we do several things. We take them when they are with us the first two months and show them

through the activities of the school, where we have fifty or sixty different activities, where they can see things quickly. It was only a short time ago, in the course of one of our trips, as we took the boys out in a group visiting, there were three boys on one trip that agreed to become apprentices.

C. B. CONNELLEY: We have given a little light on this suburban condition in Chicago. The federal government under the Smith-Hughes bill gives a certain amount of money for vocational education. Illinois gets a great deal out of it, and it does seem to me you might, through your organization, see if you couldn't get some of that money that comes directly from your state organization into your schools there. They give two million dollars that is distributed in the United States, and every dollar spent for vocational education in the state is supplemented by a dollar given by the federal government, so it is a fifty-fifty proposition.

L. A. HARTLEY: There is in each state in the United States a state board for vocational education. There is an Illinois state director for vocational education; the gentleman is J. F. Kolb. You can address him at Springfield, Ill., the capital, and Mr. Kolb will furnish you all information you desire. Instead of two million dollars I will tell you what money will be available for vocational education in the United States this next year; it will be about twenty million dollars. When you match the federal fund available in 1925 with the dollar that must be matched from the state and local funds in order to meet the Smith-Hughes Act provision you will have about twenty million dollars available in the United States, and I will say this, without hesitation, most of that money is being spent and will be spent in a haphazard manner without good direction, and it is up to you fellows to direct that spending.

R. L. COOLEY: It is true that we have a federal disposition of money to the states through the Smith-Hughes Act. It is also true that this is divided between agriculture, industry, continuation schools and apprenticeship, and all that; but when you get right down to it, it is a very measly little amount. It is intended to be begged, pure and simple. Now, the only difficulty right here is this, that in a great many communities they have felt that if they match the federal funds they are doing a one hundred per cent of matching. Aren't they? And then they say that must be adequate. One hundred per cent is all there is to this per cent business. Say, they take a penny and match a penny and do one hundred dollars' worth of work with it, and the biggest evil result that has come from this federal money being sent out into the community through the state is the assumption that in the community they have done something. We have $16,000 of that federal fund in the city of Milwaukee, and we have $841,000 in our budget on this one particular piece of work.

A MEMBER: Mr. Chairman, doesn't this resolve itself into this one thing, that the manufacturers in the country are selfish; they have to open up and loosen up. They have to take this matter at heart; they have to have the mechanics, and we have to make them and we have to train them along the lines they will be interested in. Take a young man in and train him and put him to work to get the output and not show him or give him any encouragement along the line; his spirit is soon killed and out he goes. It is to my thought that selfishness has to be broken down between manufacturers and apprentices. We have to give the young man the opportunity, and that can only be accomplished by manufacturers in general opening up a little. Of course, there are probably small manufacturers living here that perhaps are having hard time to meet their notes; they say, "We can't do anything, we can't adopt that plan." To my thought it has to be taken up in the community the same as Milwaukee has taken it up, and the way it is brought before us today, if these papers discussed today were presented to the senators of the United States, there is no doubt but what it would bring results very shortly.

W. D. MOORE: I happen to be from the South. I think we have heard from every section of the country except the South. Our local situation is such there that apprenticeship means very much more to us than to you folks. We have done a great deal on our premises along the cast iron pipe line. It comes down to the individual problem; briefly, the Lord helps them that help themselves. I believe the gentleman who speaks for a plant in a small community will find the solution a little quicker and in an ideal way if he will proceed along the line of what you can do instead of what you can't do. We have found that to be true. I might quote our aim in this thing. I believe I am quoting Roundtree of England; he says, "The solution is that you make the conditions in your shop such they will be fit for your boy; then they are probably good for the other fellow's boy." That is what we are trying to do; we are trying to make our apprenticeship training, the conditions in our shop and everything, so they will be fit for my boy. If they are fit for my boy, they will be all right for the other fellow's boy, and we will be able to distinguish the boys from the dirt.

LUCIAN H. KNAPP: I would like to add one word. We found and came to the conclusion the problem was up to the manufacturer. You will find the school authorities will co-operate, and will be glad to co-operate. You will find some of the school authorities, some of the old-fashioned schoolmasters that do not believe in vocational education, they don't consider it is necessary at all. They want to make lawyers and doctors out of all of them, but if the manufacturers will get back of it you will find that you will get the co-operation that you desire.

Progress Report of Refractories Committee

The committee meeting at Chicago decided the best procedure of our committee was to make a survey of the foundry field by collecting samples of refractories from various sources, these samples to represent or consist of specimens that had given satisfactory service in routine plant operation. Also sample of other refractories that had failed to give satisfactory service.

After these samples had been collected it was intended to send them to the Bureau of Standards for further investigation to determine the causes of failure and other information, so that these various samples could be classified for future reference by our committee. Also it was considered important that an approximate survey of replacement of refractories used in foundry practice per year be obtained, this idea being to present to Mr. Hoover of the bureau the amount of replacement to obtain his permission to allow the bureau to function in full for this committee.

However, we have been unsuccessful in obtaining this information, as the manufacturers and producers will not divulge such information, but we believe we are very safe in stating that replacement work of refractories will run 95 per cent.

There are several committees functioning on about the same lines as our refractory committee of the A. F. A., and so it seems to be a duplication of work as to the making of a survey of the field, and it is the sentiment of this committee that if the refractory committees of the different societies and associations could co-ordinate their efforts by the appointment of a controlling committee, which would consist of one representative from each of the various committees now working along the same lines, it would simplify procedure, produce results, broaden the scope of the work, prevent duplication of effort and eliminate bias reports.

If the consent of the association can be obtained, to this plan, our committee will proceed to get in touch with these various other associations and societies, with the effort to have this controlling committee formed, and to allow it to take up the detailed work of refractory research, the findings and conclusions of this control committee to be turned over to the various refractory committees of the different associations.

Our efforts on collection of samples met with partial success, and these efforts are still progressing.

Also we desire the privilege of securing various papers from members of the different refractory committees to be read at the next meeting of the A. F. A., for open discussion, these papers to be submitted in ample time for proper acceptance through the regular routine.

C. N. RING, *Chairman*
J. L. CUMMINGS, *Secretary*

Supplementary Report of the Sectional Committee for Abrasive Wheel Safety Code Submitted at the Rochester Convention, 1922

The specifications for protective hoods as adopted by the Committee* was for all wheels operating at a speed of not faster than 7,000 surface feet per minute. Hoods constructed in accordance with these specifications have proven to meet all requirements.

Attention having been called that a few wheels were being operated at a speed of 10,000 surface feet per minute, it was deemed best by the sponsor bodies to amend the code by adding specifications covering the need to meet this higher speed. This amendment does not in any way affect the present code, excepting in connection with the use of wheels which are operated at speeds in excess of 7,000 surface feet per minute, and such hoods shall be designated as "special" type. Specifications for this special type of hood, as well as for the standard hood, can be obtained from all grinding wheel manufacturers.

This amendment has been approved by the Grinding Wheel Manufacturers' Association and the Sectional Committee, and has been submitted to the American Engineering Standard's Committee for final approval.

C. H. GALE, *A. F. A. Representative*

*Trans., A. F. A., vol. 30, pp. 741-2, 1923.

Report of Committee on Corrosion of Metals

To the Members of the American Foundrymen's Association:

Your Committee on the Corrosion of Metals, which was directed to cooperate with other bodies such as the Corrosion Committee of the National Research Council, the Corrosion Committees B-3 and A-5 of the American Society for Testing Materials and the U. S. Bureau of Standards, has held four meetings since the last convention of the American Foundrymen's Association.

The membership of your committee was increased from three to five men. Each individual on the committee has been actively engaged throughout the year in some one or more phases of corrosion work, but the committee itself has viewed more particularly the practical problems involved rather than those dealing with pure science.

H. S. Rawdon, one of your committee members who is also chairman of Sub-Committee VII of A-5, American Society for Testing Materials, on "Accelerated Corrosion Tests," contributed very valuable information on "Types of Apparatus used in Testing the Corrodibility of Metals." We are especially glad to refer to the recently published corrosion reports and papers of the American Society for Testing Materials because of the fact that the individual members of your committee have furnished either time, counsel or valuable printed discussions on corrosion to that society. It is gratifying, therefore, to report that your committee is properly functioning in accord with the purpose for which it was created. In the comprehensive corrosion research work that has been planned during the year and in which your committee has cooperated, the point of view of the practical foundryman has not been overlooked.

Some of the work of the U. S. Bureau of Standards on "Soil Corrosion" is to be described for the first time by Kirk H.

Logan, a member of your committee, in a progress report presented at this meeting.

Although your committee was originally appointed to cooperate with other bodies who are actively engaged in corrosion research, the need for some data on the comparative resistance to corrosion obtained from accelerated or short time tests to parallel long time tests on cast steel, malleable cast iron and gray cast iron became manifest, and arrangements were made to carry out a preliminary set of spray or mist tests at the laboratory* of the American Cast Iron Pipe Company, Birmingham, Alabama. The results indicate that the method is satisfactory but there is need for a repetition of the work and also the checking of results so obtained with results from the long time tests. In the committees' opinion this will require several years before definite conclusions may be drawn.

Accelerated Spray Tests on Cast Iron, Cast Steel and Malleable

In order to get a comparison between the corrosion resistance of some of the ordinary commercial ferrous products, a set of representative specimens were obtained of (1) "close grained" and (2) "open grained" gray cast iron, (3) ordinary "low-test" malleable cast iron, (4) "high-test" or "certified" malleable iron, (5) "low carbon" cast steel (unannealed), (6) "low carbon" cast steel (annealed), (7) "low carbon" steel slightly worked or forged, (8) "low carbon" steel with highly deformed grain structure, (9) ordinary "low carbon" steel machine bolt. It will be noted that the terms used above are arbitrary, but have been selected to be as descriptive of well known commercial articles as possible.

Preparation of Specimens

The specimens were prepared with the idea of placing them on a small glass rack inside of a 24 inch x 24 inch x 12 inch spray box where the surface of each specimen was to be exposed in an equal degree to the various conditions that were to be maintained within the box.

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*The work being done by Mr. J. T. MacKenzie, Chief Chemist, American Cast Iron Pipe Co.

Each specimen was cylindrical in shape and approximately one inch long by three-quarter inch diameter. Those that had their original casting or mold surfaces removed were each machined in the same die, which die produced a standard ¾-inch bolt thread. The total surface area exposed was approximately four square inches for each specimen. Certain of the specimens that are indicated as unmachined were prepared with parts of their surfaces simply as they came from the molds without removing the outer so-called "skin" or chilled structure of the metal. The purpose of adopting a threaded surface for the machined specimens was (1) to increase the exposed area, and (2) to give a relatively wide variation in the character of the exposed surface. The purpose of leaving some of the foundry "skin" on some of the specimens was to learn whether or not there would be revealed in this test any wide difference in corrosion resistance between machined and unmachined castings.

Before the specimens were placed in the spray box, they were numbered by means of a metal stamp, then accurately weighed to the closest decigram, calipered and measured for total exposed surface, weighed under water for specific gravity and finally microphotographs were made of the representative specimens. Physical determinations were made a major factor rather than the chemical, but in a more comprehensive program we would certainly recommend that chemical analyses be run in order to find the limiting ranges of the commercial articles.

There is nothing unusual about the microphotographs, but they are given as a record of those metals tested.

Description of Spray Test

On December 3, 1923, all specimens were placed in the box and a mist or spray from a 20 per cent water solution of sodium chloride was produced by means of compressed air. The artificial mist thus created resembled a natural dense fog such as might be seen rolling landward along the seashore. The top of the box was covered with a glass plate so that the contents inside of the box might be inspected at frequent intervals. As all of the specimens were placed in the same box and all were

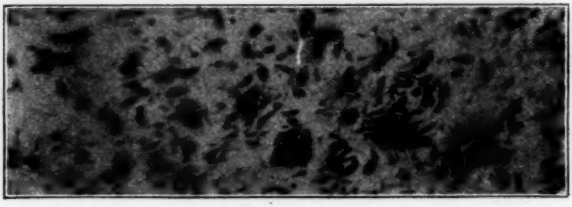


FIG. 1—OPEN GRAINED CAST IRON X 50 (UNETCHED)

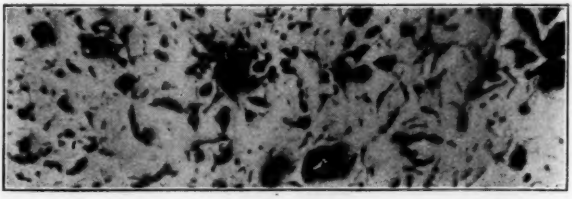


FIG. 2—CAST IRON ANNEALED AT 1800° FAHR. X 50 (UNETCHED)

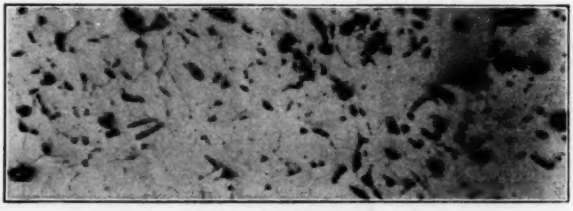


FIG. 3—CLOSE GRAINED ELECTRIC CAST IRON FROM BASIC BOTTOM FURNACE X 50 (UNETCHED)

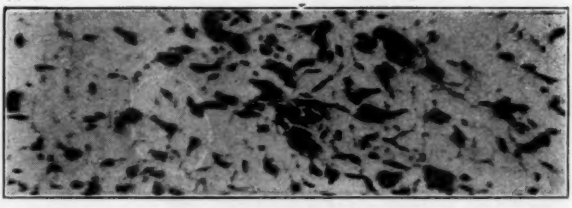


FIG. 4—CLOSE GRAINED ELECTRIC CAST IRON FROM ACID BOTTOM FURNACE X 50 (UNETCHED)

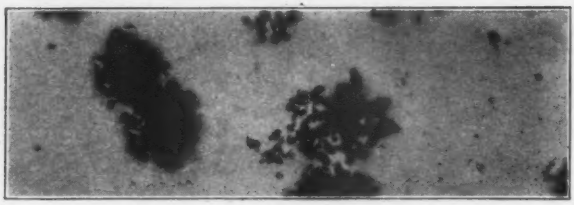


FIG. 5—LOW TEST MALLEABLE X 50 (UNETCHED)

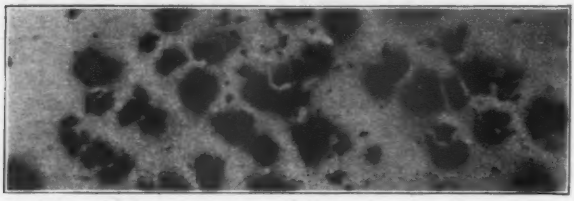


FIG. 6—CERTIFIED OR HIGH-TEST MALLEABLE X 50 (UNETCHED)

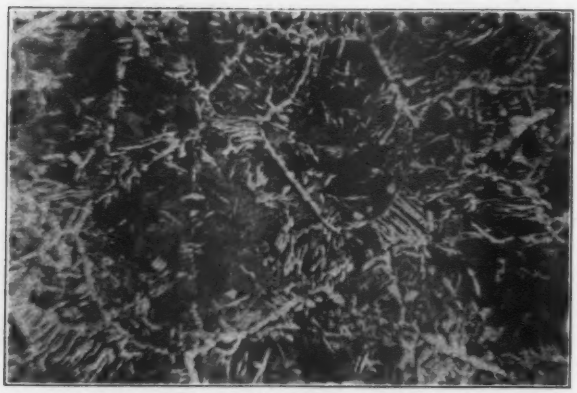


FIG. 7—CAST STEEL UNTREATED X 50 (PICRIC ACID ETCH)

FIG. 8—ANNEALED CAST STEEL (PICRIC ACID ETCH)

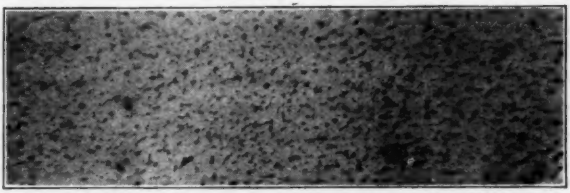


FIG. 9—SLIGHTLY FORGED CAST STEEL X 50 (PICRIC ACID ETCH)

FIG. 10—CAST STEEL WITH GREATLY DEFORMED GRAIN STRUCTURE X 50 (PICRIC ACID ETCH)

FIG. 11—ORDINARY STEEL MACHINE BOLT FROM STOCK X 50 (PICRIC ACID ETCH)

Table 1

Specimen Number	Description of Metal	Specific Gravity of Specimen	Yearly* Loss Oz. per Sq. ft.	Average Yearly Loss Oz. per Sq. ft.
1	Open Grained Cast Iron with machined surfaces	7.2	10.40	
2	Open Grained Cast Iron with machined surfaces	7.2	11.22	
3	Open Grained Cast Iron with machined surfaces	7.2	11.32	10.98
19	Open Grained Cast Iron with casting "skin" intact	7.1	9.38	
20	Open Grained Cast Iron with casting "skin" intact	7.1	9.38	
21	Open Grained Cast Iron with casting "skin" intact	7.1	12.04	10.26
29	Open Grained Cast Iron with machined surfaces annealed at 1800° Fahr.	6.9	10.20	
30	Open Grained Cast Iron with machined surfaces annealed at 1800° Fahr.	6.9	10.30	
31	Open Grained Cast Iron with machined surfaces annealed at 1800° Fahr.	6.9	10.71	10.40
32	Close Grained Cast Iron made in Basic Bottom Electric Furnace	7.2	10.61	
33	Close Grained Cast Iron made in Acid Bottom Electric Furnace	7.2	12.04	11.32
4	Low-test Malleable with machined surfaces	7.0	13.77	13.77
22	Low-test Malleable with casting "skin" intact	7.2	11.32	11.32
5	Certified Malleable with machined surfaces	7.3	12.14	
6	Certified Malleable with machined surfaces	7.3	12.55	12.34
23	Certified Malleable with casting "skin" intact	7.4	10.20	
24	Certified Malleable with casting "skin" intact	7.4	12.04	11.12
13	Cast Steel (untreated)	7.8	12.65	
7	Cast Steel (untreated)	7.6	10.51	
8	Cast Steel (untreated)	7.6	12.55	
9	Cast Steel (untreated)	7.6	12.75	12.16
10	Cast Steel (annealed)	7.6	12.95	
11	Cast Steel (annealed)	7.7	12.75	
12	Cast Steel (annealed)	7.8	11.02	12.24
14	Cast Steel (untreated, slightly forged)	7.8	13.87	13.87
15	Cast Steel (untreated, greatly deformed Grain Structure)	7.8	14.79	14.79
16	Steel Machine Bolt from stock (greatly deformed Grain Structure)	7.8	13.67	
17	Steel Machine Bolt from stock (greatly deformed Grain Structure)	7.8	13.67	
18	Steel Machine Bolt from stock (greatly deformed Grain Structure)	7.8	13.97	13.63

*The results of this test were originally calculated in grams per square inch but the figures in this table are converted to the same units as used by the U. S. Bureau of Standards for results of corrosion loss from soil tests. It is of considerable interest to note that average results from the quick time spray tests are approximately ten times the average results from soil corrosion.

kept under identically the same conditions, no effort needed to be made to maintain a uniform temperature in the box. Care was taken to expose all specimens equally; the position of the specimens in the box was periodically shifted. On December 10th, or just seven days after starting the spray in the box, the air was shut off, the salt water drained out and then for the next week the box was left entirely open to the room atmosphere and the specimens dried out. On December 17th distilled water was put into the box and the air again turned on, but this time instead of being a "salt" spray the mist was produced from distilled water. This condition was applied for seven days after which the box was allowed to dry out again for the next seven days. This cycle of one week on salt spray, one week drying, one week on distilled water spray and one week drying, was repeated until July 9, 1924. On July 10th the specimens were removed from the box, cleaned and weighed. The results are shown in table presented herewith.

While your Committee is well convinced that conclusions should not be drawn from the results of this preliminary corrosion spray test, nevertheless much can be said in favor of the method of testing which was employed.

Recommendations

Perhaps one other element should have been introduced at the beginning of this spray test that would have made it more nearly parallel actual underground service conditions. It will be noted that the cycle of alternate spraying and drying covered four weeks, that sodium chloride was used for one spray and distilled water for another spray. It is obvious that there should also be used some material consisting of dilute soil acids, perhaps a mixture of carbonic acid and humic acid, etc.

Your Committee recommends that the work be repeated on other specimens cut from the larger samples of commercial metals now being investigated in this country, by the U. S. Bureau of Standards, and the Corrosion Committees of the American Society for Testing Materials if such specimens can be obtained.

Acknowledgments

Your Committee desires to express its thanks to all those who have contributed commercial specimens for test purposes and especially to the U. S. Bureau of Standards and the American Cast Iron Pipe Company for the help rendered the Committee in connection with the preliminary set of spray tests, the results of which are made a part of this report.

Respectfully submitted,

GEORGE K. ELLIOTT,
KIRK H. LOGAN,
H. S. RAWDON,
WALTER WOOD,
H. Y. CARSON, *Chairman*

Discussion—Corrosion of Ferrous Metals

E. TOUCEDA: I have some remarks to make in view of the data that have been presented, which has to do with certain inconsistencies and incompatibilities in the figures which I have seen. Now, in the first place, in the case of low grade malleable iron, the only difference between certified malleable and low grade malleable is in the carbon content, the percentage of carbon. It would seem, therefore, that the more carbon there would be in the material the slower the rate of corrosion ought to be, whereas the figures here show that it is higher. Now, the great mass of low grade malleable is just the same as in the certified malleable.

Now, another point is this. I happened to be in the steel business a good many years ago, at a time when you might say that the Bessemer process was being developed. At that time the company with which I was connected had about 60 puddling furnaces, and the billets that were sent to the shop to be converted into wire were made of wrought iron, not steel. Then the cost of wrought iron went to such a price that it was prohibitive, and we sent them .08 carbon steel. In the course of about six or eight months complaints began to come in that the telegraph wire and fence wire was rusting. It just deteriorated in some six months, whereas the wrought iron wire lasted three or four or five years. Now, when we investigated we found that the entire trouble was due to the manganese. Malleable iron rarely has a manganese content in excess of .10; wrought iron in excess of .45. Malleable iron is essentially a low manganese product, in which the manganese might average around .22.

So it would appear as if malleable iron ought to rust at a slower rate than the average steel. Now, in all cases here it shows that where the sample has been machined the rusting has increased over the unmachined sample. I believe that is absolutely so, but I don't believe that the reason for it is just what has been attributed; that is, that it is due to the skin.

I think that it is due to the strain of machining. You take a small piece of steel and bend it, or any other material, cold bend it, and you expose that to rust, you will find that the rust is very much higher at the point where the strain has taken place. I think that one of the reasons—it may not be the entire story, but one of the reasons—that a machined casting rusts faster than one that isn't machined is due to the strain of the machining tool on the work. No analyses have been given here. I would like to ask if any of these steel products listed here contain copper.

H. Y. CARSON: The analyses indicated no copper.

A MEMBER: We have been conducting some tests for the past sixteen years or more in two classes; an exposure test to the atmosphere and a ground or soil test. We started in on it without any background particularly, because that long ago not much had been done, so a perfect description of the specimens and the procedure to be followed should be given to go along with the figures which we have. The specimens were plates approximately 3/16 inches thick. The test was started some years before I took over, eight years ago. I don't know the exact dimension, but that is close, plates about 8 inches wide and 16 inches in length. The plates which were exposed were hung on a ladder between two bays, on the roof of a foundry building. The buried specimens were placed on edge in the ground, the top of the specimens 18 inches from the surface. The soil was a gravel, or sand and gravel. Our procedure has been to take those plates anually, in October, brush them, dry the ones that were buried, brush them to remove loose scale, and weigh accurately, as accurately as we could plates of that size, to hundredths of a pound. It is obvious, I think, that all of these specimens, except possibly the rolled, were machined, because the dimensions would not probably represent the cast; particularly the cast steel 3/16 inch in a plate of that size would hardly have been practical 16 years ago. The cast iron shows in the exposure test at the end of 16 years 3.05 per cent loss in weight; malleable iron, 2.11 per cent loss in weight; cast steel, 2.19 per cent loss in weight; wrought iron, 3.07 per cent loss. Of the samples, grey iron showed .73; malleable, .56; cast steel, .66, and wrought iron, .66 per cent. Now, perhaps we can't accept those figures as representing the true merits of the materials, because we haven't duplicated service conditions. Taking up the samples and weighing them and brushing them doesn't represent what would apply in a bridge structure or any building structure—any exposure. However, I think the figures do give some idea of the results.

Discussion—Report of Committee on Corrosion

By H. A. Schwartz, Cleveland, Ohio

The results of corrosion tests, especially when accelerated, are almost proverbially erratic. There is also always grave doubt as to whether the result of any such test simulates a natural condition sufficiently to warrant any very firm conclusions as to what may be expected under working conditions.

Table 1

CORROSION LOSS OF VARIOUS FERROUS MATERIALS ON EXPOSURE TO THE INDICATED MEDIA

Exposure	Loss in Grams Per Square Centimeter Per Year					
	W I[1]	C I[2]	E S[3]	M1[4]	M2[5]	C S[6]
1—Ocean Water (submerged)	.008	.009	.031	.007	.007	....
2—No. 1 cleaned and exposed a second year	.034	.029	.010	.023	.023	....
Average of above	.021	.019	.020	.015	.015	....
3—Ocean Water (spray in air)	.102	.106	.102	.084	.098	....
4—No. 3 Cleaned and exposed a second year	.161	.115	.082	.114	.091	....
Average of Nos. 3 and 4	.132	.111	.092	.097	.095	....
Average of No. 4 two consecutive years	.135	.104	.096	.094	.098	....
5—Lake Water (submerged)	.000	.009	.000	.014	.014	....
6—No. 5 Cleaned and exposed a second year.	.039	.039	.043	.030	.030	....
Average of Nos. 5 and 6	.020	.024	.022	.022	.022	....
7—Lake Water (spray in air)	.016	.009	.018	.014	.014	....
8—No. 7 Cleaned and exposed a second year	.038	.019	.034	.015	.019	....
Average of Nos. 7 and 8	.027	.014	.026	.015	.017	....
Average of No. 8 two consecutive years	.016	.014	.018	.022	.015	....
9—Water Vapor (atmospheric pressure)	.002	.0004	.0007	negative		
10—Weather one year	....	.038	.030	.024	.015	.060
11—No. 10 Two consecutive years	....	.025	.019	.017	.010	....
13—No. 10 Three consecutive years		.020	.014	.010	.009	....

[1]W I, wrought iron pipe.
[2]C I, soft cast iron.
[3]E S, low carbon electric cast steel.
[4 and 5] M1 and M2, two different lots of malleable cast iron.
[6]C S, low carbon open hearth cast steel.

These facts are recognized in the report, but are here referred to again in order to explain the reason for submitting the results of certain long-time tests which form a part of the

program of the study of corrosion in the research department of the National Malleable and Steel Casting Co.

Table 1 is no doubt self-explanatory. The conclusions in some cases are not in agreement with the results obtained by the committee. For this, neither apology nor explanation is deemed necessary. The cause resides in the inherent complexity of the entire problem, making it practically impossible for two different methods of experiment to give identical results. We merely do not know how to make the conditions similar unless we make them identical.

The purpose of presenting the present data is merely to render available an independent series of observations.

Soil Corrosion Investigation[1]

By K. H. Logan,[2] Bureau of Standards, Washington, D. C.

Part I

Introduction

A. Reasons for Tests: In the course of their studies of stray current electrolysis, engineers of the Bureau of Standards have had their attention called to cases of corrosion, in which the electrical measurements taken at the time the corrosion was discovered, apparently did not account for the corrosion. In such cases, data indicating the extent of the corrosion which might be attributed to soil conditions would be very helpful. The Bureau of Standards, therefore, started an investigation of the action of soils on buried pipes.

B. Interests Cooperating: In this work the cooperating interests are: The Research Subcommittee of the American Committee on Electrolysis, through which, in many cases, sites and labor for burying specimens were secured from utilities represented on the Committee; The Bureau of Soils of the Department of Agriculture, which made the selection of soils and the determination of their physical and chemical properties; Manufacturers of pipes and pipe coatings who furnished materials to be tested; and the utilities and organizations who furnished labor and sites for burying specimens.

Manufacturers That Furnished Specimens

1. American Cast Iron Pipe Co., Birmingham, Alabama.
2. American Machine & Foundry Co., 5520 Second Ave., Brooklyn, N. Y.
3. American Rolling Mill Co., Middletown, Ohio.
4. Brown Company, Portland, Maine.
5. A. M. Byers Company, Pittsburgh, Pa.
6. Calorizing Company, Pittsburgh, Pa.
7. Duriron Company, Dayton, Ohio.
8. Jones & Laughlin Steel Co., Pittsburgh, Pa.
9. Mueller Mfg. Company, Decatur, Ill.
11. National Carbon Company, Long Island City, N. Y.

[1]Published by permission of the Director, Bureau of Standards.
[2]Electrical Engineer with the Bureau of Standards.

12. National Tube Company, Pittsburgh, Pa.
13. Nugent Steel Castings Co., Chicago, Ill.
14. Pittsburgh Valve, Foundry & Construction Co., Pittsburgh, Pa.
15. Reading Iron Company, Reading, Pa.
16. Republic Iron & Steel Co., Youngstown, Ohio.
17. Standard Underground Cable Co., Perth Amboy, N. J.
18. Steel & Tube Company of America, Chicago, Ill.
19. Stockham Pipe and Fitting Co., Birmingham, Ala.
20. U. S. Cast Iron Pipe & Foundry Co., Burlington, N. J.
21. Western Electric Company, New York City.
22. Youngstown Sheet & Tube Co Youngstown, Ohio.
23. Habershaw Electric Co., New York, N. Y.

Manufacturers That Furnished Pipe Coatings

1. American Tar Products Co., 208 S. LaSalle St., Chicago.
2. Barber Asphalt Company, Maurer, N. J.
3. Barrett Company, 40 Rector St., N. Y. City.
4. Pioneer Asphalt Company, Laurenceville, Ill.
5. H. H. Robertson Company, Pittsburgh, Pa.
6. Standard Oil Co. of Calif., San Francisco, Calif.
7. The Texas Company, 17 Battery Place, N. Y. City.
8. United Gas Improvement Co., Philadelphia, Pa.

Organizations That Furnished Labor and Sites

Alexandria Water Co., Alexandria, Va.
City of Atlanta, Ga. Ry. & Power Co. Atlanta, Georgia.
San Joaquin Light & Power Co., Fresno, Calif.
City of Baltimore, Baltimore, Md.
Standard Pipe Line Co., Shreveport, La.
Camden Water Dept., Camden, N. J.
Midwest Refining Co., Casper, Wyoming.
Union Gas & Elec. Co., Cincinnati, Ohio.
City of Cleveland, East Ohio Gas Co., Cleveland, Ohio.
Dallas Gas Co., Dallas, Texas.
Tri-City Ry. & Light Co., Davenport, Iowa.
Denver Gas & Elec. Co., Denver, Colo.
Des Moines Gas Co., Des Moines, Iowa.
Standard Oil Co. of New Jersey, Elizabeth, N. J.
Union Light, Heat & Power Co., Fargo, N. D.
Phila. Suburban Gas & Electric Company, Jenkintown, Pa.
Jacksonville Gas Co., City Commission of Jacksonville, Fla.
Kansas City Gas Co., Kansas City, Mo.
So. Calif. Gas Company, Los Angeles Gas & Elec. Co., Los Angeles, Calif.
Memphis Artesian Water Co., Memphis, Tenn.
Meridian Lt. & Ry. Co., City of Meridian (Water), Meridian, Miss.
City of Middleboro, Middleboro, Mass.
Milwaukee Gas Light Co., City of Milwaukee, Milwaukee, Wisconsin.
Mobile Water Works, Mobile, Alabama.
New Orleans Ry. & Lt. Co., Sewerage & Water Board, New Orleans, La.
Counties Gas & Elec. Co., Norristown, Pa.
City of Norwood, Mass.
Boston Consolidated Gas Co., Boston, Mass.
East Bay Water Co., Oakland, Calif.
Omaha & Council Bluffs Electrolysis Committee, Omaha, Nebraska.
Pueblo Gas & Fuel Co. Pueblo, Colorado.
City of Rochester, Rochester, N. Y.
Utah Gas & Coke Co.,

Salt Lake City, Utah.
San Antonio Public Service Co., San Antonio, Texas.
San Diego Consolidated Gas & Elec. Co.,
San Diego, Calif.
City of Seattle, Seattle, Washington.
Tide Water Pipe Line Co., Bradford, Pa.
City of Springfield, Springfield Street Ry. Co., Springfield, Ohio.
St. Paul Gas Lt. Co., St. Paul, Minn.
Wilmington Gas Co., Wilmington, Delaware.

C. Locations and Grouping of Tests: The Bureau of Soils selected or approved the following forty-six locations and soils as typical of soil conditions throughout the United States:

STATE	CITY	SOIL
Alabama	Mobile	Norfolk Fine Sandy Loam
California	Bakersfield	Black Alkali in Hanford Fine Sandy Loam
California	Buttonwillow	White Alkali
California	Los Angeles	Hanford Fine Sandy Loam
California	Los Angeles	Ramona Loam
California	San Diego	Adobe Soil
California	Oakland	Dublin Clay Loam
Colorado	Denver	Unidentified Sandy Loam
Delaware	Wilmington	Sassafras Silt Loam
Florida	Jacksonville	Norfolk Sand
Florida	Jacksonville	St. John Sand
Georgia	Atlanta	Cecil Clay Loam
Iowa	Davenport	Muscatine Silt Loam
Iowa	Des Moines	Lindley Clay Loam
Louisiana	Bunkie	Swampland
Louisiana	New Orleans	Muck
Louisiana	New Orleans	Clay
Maryland	Baltimore	Hagerstown Sandy Loam
Massachusetts	Middleboro	Gloucester Sandy Loam
Massachusetts	Norwood	Merrimac Gravelly Sandy Loam
Minnesota	St. Paul	Hempstead Silt Loam
Mississippi	Meridian	Ruston Fine Sandy Loam
Mississippi	Meridan	Susquehanna Clay
Missouri	Kansas City	Summit Silt Loam
Missouri	Kansas City	Marshal Silt Loam
Nebraska	Omaha	Wabash Silt Loam
Nebraska	Omaha	Knox Silt Loam
New Jersey	Camden	Sassafras Gravelly Sandy Loam
New Jersey	Elizabeth	Salt Marsh
New York	Rochester	Ontario Loam
North Dakota	Fargo	Fargo Clay Loam
Ohio	Cincinnati	Fairmount Loam
Ohio	Cleveland	Allis Loam
Ohio	Cleveland	Mahoning Silt Loam
Ohio	Sidney	Genesse Silt Loam
Ohio	Springfield	Miami Silt Loam
Pennsylvania	Jenkintown	Chester Loam
Pennsylvania	Norristown	Penn Silt Loam
Tennessee	Memphis	Memphis Silt Loam
Texas	Dallas	Bell Clay
Texas	San Antonio	Houston Black Clay
Utah	Salt Lake City	Clay
Virginia	Alexandria	Keyport Loam

Washington	Seattle	Everett Gravelly Sandy Loam
Wisconsin	Milwaukee	Peat
Wisconsin	Milwaukee	Miami Clay Loan
Wyoming	Casper	Alkali Soil

A set of specimens was buried in each of the locations just mentioned. The specimens comprising each set were divided into six identical groups, so buried that one group might be uncovered at a time without disturbing the others.

With the extension of the investigation to cover tests of protective coatings, brass fittings, and a few other materials, it became impracticable to bury complete sets in every location. Therefore, six locations, embracing six different soil conditions, were selected, at which complete sets, covering all phases of the investigation, were buried. The soils in these locations include:

1. Black alkali
2. White alkali
3. Salt marsh
4. Acid soil (muck)
5. Clay
6. Gravelly soil

Specimens comprising each large set were divided into four identical groups. Smaller sets containing specimens of bituminous coatings, metallic coatings, and brass fittings, were buried in the remaining forty locations. Small sets were also divided into four identical groups. It is the intention of the Bureau of Standards to uncover one group of each set at intervals of two or three years, extending over a period of about ten years. The uncovered specimens will be shipped back to Washington and will be available for examination in the corrosion laboratory of the Bureau of Standards.

Part II

Tests of Pipe Materials

A. First Series of Burials: In the first series, specimens were buried in the forty-six locations previously mentioned.

1. Kinds of Material: The following materials were included:

Armoured cable
Butt welded bessemer steel (2 sources)
Butt welded wrought iron

Cast iron from southern mines
Cast iron from northern mines
Centrifugal cast iron (De Lavoud process)
Copper bearing open hearth steel
Duriron
Fiber pipe (for water and gas mains)
Ingot iron
Lap welded bessemer steel
Lap welded open hearth steel
Lap welded wrought iron
Lead cable sheath (small per cent antimony)
Lead pipe.

2. *Size and Arrangement of Specimens:* The iron and steel specimens were six inches long and from one and one-half to six inches in diameter. To avoid difficulties of protecting the insides of pipes from corrosion, the amount of which could not be determined, the pipes were filled with the same kind of earth which surrounded them. The cut ends of the pipes were covered with asphalt to prevent galvanic action and to protect the identification numbers. The specimens of lead cable sheath and lead pipes were flattened into sheets to facilitate handling. These sheets were 22 inches x 8 inches (sheaths) and 22 inches x 4 inches (pipes). The armoured cable was 22 inches long and 1 inch in diameter. In general, six groups containing two specimens of each material were buried in each test locality, in order that one group at a time might be uncovered without disturbing the others. The first examination of specimens took place in 1923, about one year after they were buried.

B. Second Series of Burials: Specimens received subsequent to the burial of the first sets were buried at the time the first groups were uncovered.

1. *Kinds of Material:* The following materials

Cast iron
Centrifugal cast iron (2 kinds)
Cast steel
Machined cast iron and centrifugal iron

Malleable cast iron
Semi-steel

were buried in the locations listed below:

Bakersfield, California
Casper, Wyoming
Elizabeth, New Jersey
Meridian, Mississippi
New Orleans, La.
Norwood, Mass.

2. *Size and Arrangement of Specimens:* The specimens were six inches long and from two to six inches in diameter. The cast steel specimens were in the form of elbows, and the malleable cast iron in the form of bends. The cut ends of the pipes were coated with asphalt to prevent galvanic action and to protect the identification numbers. Four groups, containing two specimens of each material, were included in each of the large sets buried at the six locations mentioned.

Part III

Tests of Protective Coatings

A. First Series of Burials: At the request of a certain pipe manufacturer, two specimens each of five coatings were buried in most of the localities chosen for pipe tests.

1. *Kinds of Material:* Specimens coated with the following materials were included:

Galvanized coating
Coal tar dipped coating
Coal tar dipped "fabric" coating
Asphalt dipped coating
Asphalt dipped "fabric" coating.

2. *Size and Arrangement of Specimens:* Specimens having protective coatings were about two feet long, and two inches in diameter. There were two specimens of each kind, all buried in a group at one end of a trench.

B. Second Series of Burials: The coated specimens, listed above, were not sufficient to furnish all the data desired, and the original investigation was, therefore, extended to include a more thorough study of protective coatings, with a view to determining the life and efficiency of coatings when applied to different pipe materials and when exposed to various soil conditions.

1. Kinds of Material

Two general classes of coatings are being tested, namely, bituminous dips and metallic coatings. Since it was necessary to limit the tests to those materials which promise the best results and which are most dependable and available, it was necessary to exclude paints, patented preparations, and coatings which are not available commercially. The bituminous coatings most commonly used are made from asphalts or coal tar pitch.

Bituminous Coatings

1. Asphalt Coatings: Tests of six asphaltic dips should give a fair idea of the usefulness of this type of material. The asphalts selected include: Mexican, Texas, California, Midcontinent, a mixture of Midcontinent, Gilsonite and Stearin Pitch, and a mixture of Midcontinent and Gilsonite. These tests should show the durability of the coatings under the six different soil conditions. In addition, Mexican Asphalt is being tested in each of the forty other locations where bare pipes have been placed. This type was selected as it was available in the largest quantities at that time. From this information it will probably be possible to estimate the behavior of asphaltic coatings.

2. Pitch Coatings: Tar pitches are derived from three principal sources and may be classified as low carbon (coke oven), high carbon (gas house coal tar), and water gas. All of these are being tested in each of the six locations previously mentioned in this outline, and in addition, one kind of pitch is being tested in each of the forty other locations. For this purpose high carbon pitch was selected, chiefly on account of the better appearance of the coating obtained from it.

All coatings were applied at the optimum temperature by the hot dip process, and the pipes were dipped twice to eliminate

pinholes, they being drawn from the dip bath at such rate that no drip occurred. The dipped pipes were 17 inches long and 1½ inches in diameter. Bessemer steel was the pipe material used.

3. Fabric Wrapped Specimens: The use of asphalt or pitch impregnated fabric to protect pipe is common, and to determine the relative value of such a coating four specimens of pipe protected by fabric, treated with one asphaltic material, have been buried in twenty-three locations.

Metallic Coatings

Zinc, lead, aluminum, and tin have been used to protect iron against corrosion due to atmospheric conditions, but zinc applied as galvanizing has been the chief metallic protection against soil corrosion. Lead and aluminum coated pipes are also available.

1. Galvanized Pipes: The effect of two possible variables, thickness of the coating and character of base materials, will be determined.

Effect of Thickness of Galvanizing: Since it was not possible to accurately predetermine the weight of coatings applied to pipes, and since the thickness of coatings will be an important factor, it was proposed to determine the effect of this factor by burying specimens of sheet material bearing different weights of coatings. These specimens were 12 inches long and 6 inches wide, there being specimens of copper bearing sheet protected by coatings weighing, respectively, 1.5, 2.0, 2.5 and 3.0 ounces per square foot, and of ingot iron sheet protected by coatings weighing, respectively, 1.5, 2.0 and 2.5 ounces per square foot. Four each of the above named specimens were buried in each of the six locations.

Effect of Base Material: To determine the effect of base materials, eight specimens of one weight of galvanizing applied to copper bearing steel and ingot iron, and four specimens of one weight of galvanizing applied to wrought iron, were buried in each of the six types of soils previously named. Four specimens of galvanizing applied to one of these materials were buried in each of the other forty locations. The coating has

a weight of nearly 2 ounces per square foot, as it is practical to apply it without special manipulation.

2. Galvanized Sheet for Underground Tanks: The investigation of soil corrosion is primarily concerned with the action of soils on pipes. A large amount of sheet metal in the form of tanks and culverts is also exposed to soil action, and the Bureau consented to include a few tests of sheet material because it appears that such tests would be of considerable value to the public and could be conducted in connection with the pipe tests much more economically than as an independent investigation. Four specimens of Bessemer steel, copper bearing steel, and ingot iron, each protected by galvanizing of the same weight, were buried in each of the forty-six locations. As a check on the galvanized sheet, 4 specimens of black bessemer steel, black copper bearing steel, and black ingot iron were buried in the six locations previously mentioned.

3. Sherardized Bolts: In underground pipe lines and structures, bolts are frequently used in places exposed to soil action. Various protective measures have been applied to these bolts. Sixteen specimens of sherardized bolts and nuts were buried in each of the six different soils. These bolts were 6½ inches long and ¾ inch in diameter.

4. Sprayed Sheets: Commercial practice of galvanizing consists of a dipping process to obtain the zinc coating. Methods of galvanizing by a spraying process are being developed. Specimens of this type of galvanizing, treated at the Bureau of Standards, were included in the test. Four specimens each of 16 gage sheet steel, about 4 inches square, and ingot iron sheet of the same size so treated, have been buried in each of the six locations mentioned previously.

5. Lead Coatings: Eight specimens of lead coated pipe were buried in each of the forty-six locations. These pipes were 6 inches long and 1½ inches in diameter. Sixteen specimens of lead coated bolts and nuts were buried in each of the six locations. The bolts were 3 inches long and ¾ inch in diameter.

6. Calorized Pipe: Eight specimens of pipe calorized by the dry process and a like number calorized by the hot dip process, were buried in each of the six different soils. These specimens were 6 inches long and 2 inches in diameter.

2. Size and Arrangement of Specimens

To avoid confusion the size of the specimens was specified for each group in most cases. The bituminous and zinc coatings were applied to pipe 17 inches long and from 1½ to 3 inches in diameter. The zinc coated sheet, unless otherwise specified, was 12 inches long and 6 inches wide, the thickness No. 16 or 18 gage. In the case of galvanized and calorized pipes, it was observed that the protective coating on the inside of the pipes was not as uniform as that on the outside. For this reason the pipes were completely filled with asphalt, so that only the coating on the outside was exposed to the soil. All the specimens of protective coatings were divided into four identical groups and were buried at the locations previously stated.

Part IV

Tests on Brass Pipe Fittings

A. First Series of Burials: (no brass specimens buried)

B. Second Series of Burials: Brass cocks are commonly used in connection with gas and water services and it was proposed, therefore, to determine what action various soils have on different brasses, and whether the connecting of brass to iron or lead creates a galvanic couple which is detrimental.

1. Kinds of Material: Four types of cast brass and bronze are being tested under three conditions: (1) connected to lead, (2) connected to brass, (3) connected to galvanized iron.

2. Size and Arrangement of Specimens: The specimens of cast brass and bronze were in the form of caps 1½ inches outside diameter, and threaded to receive ½ inch pipe. The specimens of lead, brass, and galvanized iron were in the form of ½ inch nipples, 2 inches long, the lead being pressed together

at one end, and the brass and iron being capped at one end with the same material. The nipples were screwed into the cast caps, forming units comprising the three types of conditions mentioned above. Four groups of specimens were buried in each of the forty-six locations, each group containing twelve specimens, four of each type.

Part V

Tests of Miscellaneous Materials

A. First Series of Burials: (no miscellaneous materials buried)

B. Second Series of Burials: In addition to the specimens of pipe materials, protective coatings, and brass fittings, other specimens which are not included in these three classifications were received for test.

1. Kinds of Material:

16 specimens wrought iron bolts with nuts attached.

Specimens furnished by the Bureau of Mines, as follows:

Aluminum (2 kinds)	Copperoid steel
Brass	Duralumin
Bronze	Ingot iron
Copper	Lead (2 kinds)
	Zinc

2. Size and Arrangement of Specimens:

The wrought iron bolts were 3 1-2 inches long and 3-4 inch in diameter. They were buried in each of the six specially selected locations.

The Bureau of Mines specimens were in the form of small plates or sheets, 2 inches x 6 inches in area, and ranged from 1-16 inch to 1-4 inch in thickness. One exception was made in the case of some corrugated zinc sheet, which was about 12 inches square. A set containing specimens of each kind was buried in five of the six special locations.

Part VI

Number of Specimens Involved in Investigation

A. First Series (46 locations)

1. Pipe materials:
   46 soils x 13 materials x 12 specimens in each soil. 7,176
2. Protective coatings:
   Galvanized pipe: 46 soils x 2 specimens in each soil 92
   Bituminous coatings: 46 soils x 8 specimens in each soil 368

7,636

B. Second Series (46 locations)

6 locations

1. Pipe Materials:
   6 soils x 7 materials x 8 specimens in each soil.... 336
2. Protective Coatings:
   Asphalt coatings: 6 soils x 6 materials x 4 specimens 144
   Pitch coatings: 6 soils x 3 materials x 4 specimens 72
   Fabric wrapped coatings: 6 soils x 1 material x 4 specimens 24
   Zinc coatings:
   (galv. pipe)
   6 soils x 2 materials x 8 specimens
   6 soils x 1 material x 4 specimens } 120
   Zinc coatings:
   (sheet)
   6 soils x 1 mtl. x 4 wts. x 4 spec.
   6 soils x 1 mtl. x 3 wts. x 4 spec.
   6 soils x 4 mtls. x 1 wt. x 4 spec. } 264
   Black sheet to check galv.: 6 soils x 2 mtl. x 4 spec. 72
   Zinc coatings (sherardized bolts) 6 soils x 16 spec. 96
   Zinc coatings (shoop process) 6 soils x 2 mtl. x 4 spec. 48
   Lead coatings (pipe) 6 soils x 8 specimens..... 48
   Lead coatings (bolts) 6 soils x 16 specimens.... 96
   Calorized coatings: 6 soils x 2 coatings x 8 spec. 96

3. Brass fittings:
   6 soils x 3 types x 16 specimens..... 288
4. Miscellaneous materials:
   Wrought iron bolts: 6 soils x 16 specimens..... 96
   Bureau of Mines specimens: 5 soils x 12 mtls. x 8 specimens 480

40 locations—
Bituminous coated pipe:
40 soils x 2 materials x 5 specimens..... 400
17 soils x 1 material x 4 specimens..:..... 68
Zinc coated pipe:
40 soils x 4 specimens..... 160
Zinc coated sheet:
40 soils x 3 materials x 4 specimens..... 480
Lead coated pipe:
40 soils x 8 specimens..... 320
Brass fittings:
40 soils x 3 combinations x 16 specimens.....1,920

3,348

First Series 7,636
Second Series 2,280
3,348

Total Number 13,264

Part VII

Determination of Corrosion of Specimens

As previously stated, a set of specimens at each location will be uncovered at intervals of about two years and will be shipped to the Bureau of Standards for examination. The Bureau expects to determine the amount of corrosion in three ways, (1) inspection, (2) loss of weight, (3) measurement of depth of pits. Any other data relative to the rate or effects of corrosion will be noted. Panoramic photographs of the exposed surfaces of the specimens will be made.

Each individual specimen was submitted to the following treatments before being shipped to the field:

1. Cleaning: Whenever necessary specimens were thoroughly cleaned with gasoline.

2. Numbering: For purposes of identification each specimen was stamped with proper key letters or numbers and serial number.

3. Weighing: Each specimen was weighed, check-weighed and records kept of all the weights. In most cases specimens were weighed and checked to within twenty milligrams.

4. Pitching: The final operation, which in the laboratory is termed "pitching," consists of coating the numbers and all cut surfaces with asphalt.

When the specimens were placed in the trench the position of each piece was noted.

When the specimens are returned from the field, the above cycle of operations will be repeated, with the exception of No. 4. The loss of weight and depth of pits will be determined. Specimens will then be varnished and stored for reference. In addition to the field tests, laboratory tests are being conducted at the Bureau of Standards, using soil samples sent in from each location.

PART VIII

Discussion of the Progress Report of Soil Corrosion Investigation

Having frequently encountered serious corrosion of underground structures, the cause of which was uncertain, the electrolysis section of the Bureau of Standards started, in 1921, an investigation of the relation of soils to the corrosion of pipes, for the purpose of determining under what conditions the soil tends to destroy buried structures. The extent of the investigation and the organizations co-operating are shown in the accompanying outline of the work.

The primary purpose of the investigation was to obtain data directly applicable to the interpretation of corrosion observed in connection with electrolysis surveys. For this purpose it seemed best to approximate, as nearly as possible, conditions encoun-

tered by pipe utilities and other pipe owning companies, by selecting samples of available pipe material from stock and burying them without special treatment or preparation, in such sites as are frequently encountered by utilities.

In following such a procedure many considerations must be kept in mind. Pipe material of a certain kind is not uniform in chemical composition or mechanical properties and similar variations occur in the soil of each locality. It was thought there might be a possibility that the relation of a specimen to adjacent specimens and to the sides of the trench might affect the rate of corrosion, as might the location of the trench with respect to electric railways, drainage, and climatic conditions. The temperature and moisture conditions at the time the specimens were buried, or immediately thereafter, may determine the character of the initial corrosion products and thereby influence the entire experiment. Most of these factors, however, are precisely those which influence the corrosion of pipes in practice, and these practical conditions of pipe corrosion cannot be duplicated in the laboratory, hence the necessity of placing the specimens in the ground under the nearest possible approach to service conditions.

An investigation of this kind requires a large number of specimens for the separation of the numerous variables, the presence of which should be continually kept in mind in interpreting the results of the work. The individual effects of certain of the variables can probably be more fully determined in the laboratory where conditions are under control. For this reason numerous laboratory experiments are being carried on in parallel with the field tests in order to throw additional light on certain of the variable factors encountered.

The first specimens were buried March 1, 1922, and the burying of specimens continued irregularly throughout most of the following year. As indicated in the outline, six identical groups of specimens were buried in each location, in order that a group could be removed from time to time and the progress of the corrosion observed without interfering with the specimens to be uncovered later.

In order that the initial rate of corrosion might be observed, removal of the first groups of specimens was begun in October,

1923. Other work of the electrolysis section prevented the beginning of this work earlier, and the weather conditions made it expedient to take up the specimens in an order approximately reversed from that in which they were buried. It thus happened that some of them were buried only one year, while others two years. In order to compare the corrosion in different localities it was necessary to reduce the data to a definite rate of corrosion, and this involved the assumption that the corrosion was proportional to the time the specimens were buried. Probably this is not strictly true. The extent of the error due to this assumption will appear after the specimens subjected to longer exposure have been examined.

The results of the examination of the pipe materials removed are not such as to justify definite conclusions now concerning the relative merits of any materials under test, or as to the life of the specimens in any particular soil. The initial corrosion is undoubtedly influenced by the oxide on the specimens. What this influence is, and the effects of the initial corrosion products on subsequent corrosion, remain to be determined by a study of the specimens still in the ground.

It appears advisable, nevertheless, to make public now the results so far obtained in order that those co-operating may be kept in touch with the progress of the investigation and be given an opportunity to make such suggestions for changes, modifications, or additions as may seem desirable; and that others interested in soil corrosion may know what is being done, possibly avoiding duplication of the work.

The specimens upon which this report is based consist of eleven kinds of pipe material, two kinds of lead, and a piece of parking cable. The specimens were selected from stock, cut into 6-inch lengths, cleaned in gasoline, numbered, and weighed. The cut ends were protected against corrosion by being heated to about 200 degrees Fahr., and dipped in asphalt. The mill scale was not removed from the specimens and they received no protective coating.

At the time the specimens were uncovered the dirt adhering to them was scraped off and placed in bags for future examination. As soon as the specimens were returned from the field

to the laboratory at the Bureau of Standards they were thoroughly cleaned by scraping and by soaking in a hot solution of ammonium citrate. This procedure removed the rust but did not materially affect the mill scale except where it had been loosened by corrosion. There has been, however, a slight loss of weight due to loss of mill scale in handling and cleaning. This loss is not sufficient to be of any importance.

The accompanying table shows the average rate of corrosion and of penetration of the five deepest pits of each of the rolled metal specimens in each soil. The losses of the several materials in any one soil were quite similar, as shown in Fig. 1. For those who are interested in a more detailed presentation of the results, a table arranged according to the class of material, has been prepared, and copies can be obtained by application to the U. S. Bureau of Standards.

An examination of the specimens after cleaning shows several distinct types of corrosion with intermediate varieties. Specimens from a few locations look as if they had been immersed in dilute acid. The millscale is almost entirely removed from them and the surfaces appear bright and smooth, with few or no pits. In other locations the millscale is partly removed, and large, bright, very shallow corroded areas appear. These have been spoken of as "blotches." Specimens from one location show rather deep narrow channels, or grooves, irregular in form, and with sharp edges. In a few locations the corrosion takes the form of numerous small, deep pits, while in others the pits are few in number, but larger and deeper. A considerable number of specimens show little corrosion, except at one end or on one side, while on specimens from other localities the corrosion is fairly well distributed.

The character of the corrosion seems to have some definite relation to the soil or locality where the specimens were buried, since in general the type of corrosion is similar for all or most of the comparable specimens in any locality. So far there does not seem to be any marked superiority of any one kind of iron or steel for all soil conditions, with the exception of the high silicon alloy cast iron (14.25 silicon).

Specimens of wood fiber pipe were also removed. They can-

Table No. 1

Average Corrosion of Wrought Iron, Open Hearth Pure Iron (99.8% pure), Bessemer Steel, Open Hearth Steel, and Copper-Bearing Steel

SOIL	CITY	Avg. Loss per Yr. Oz./sq. ft.	Penetration of pits. Oz/yr. Maximum	Penetration of pits. Oz/yr. Average 5 deepest	Pitting Factor
Keyport Loam	Alexandria, Va.	1.23	....	....	.....
Cecil Clay Loam	Atlanta, Ga.	0.90	.027	.022	15.95
Black Alkali	Bakersfield, Calif.	1.96	.026	.021	7.00
Hagerstown Sandy Loam	Baltimore, Md.	0.29	.027	.023	51.80
Swampland	Bunkie, La.	0.27	....	....	.....
White Alkali	Buttonwillow, Calif.	3.60	.029	.025	4.51
Sassafras Sandy Gravelly Loam	Camden, N. J.	0.17	....	....	.....
Alkali	Casper, Wyo.	1.09	....	....	.....
Fairmount Loam	Cincinnati, Ohio	0.58	....	....	.....
Allis Loam	Cleveland, Ohio	1.21	....	....	.....
Mahoning Silt Loam	Cleveland, Ohio	1.05	....	....	.....
Bell Clay	Dallas, Texas	0.93	....	....	.....
Muscatine Silt Loam	Davenport, Iowa	0.89	....	....	.....
Unidentified Sandy Loam	Denver, Colo.	0.76	.039	.031	26.60
Lindley Clay Loam	Des Moines, Iowa	0.64	.026	.019	19.40
Salt Marsh	Elizabeth, N. J.	1.62	.029	.022	8.87
Fargo Clay Loam	Fargo, N. D.	0.62	.037	.030	31.60
Norfolk Sand	Jacksonville, Fla.	0.57	.022	.016	18.34
St. John Sand	Jacksonville, Fla.	1.16	.025	.021	11.80
Chester Loam	Jenkintown, Pa.	1.07	....	....	.....
Marshal Silt Loam	Kansas City, Mo.	1.40	....	....	.....
Summit Silt Loam	Kansas City, Mo.	0.42	.024	.019	29.50
Hanford Fine Sandy Loam	Los Angeles, Calif.	0.14	....	....	.....
Ramona Loam	Los Angeles, Calif.	0.44	....	....	.....
Memphis Silt Loam	Memphis, Tenn.	0.91	.025	.021	15.10
Ruston Fine Sandy Loam	Meridian, Miss.	0.53	.020	.016	19.70
Susqehanna Clay	Meridian, Miss.	1.50	.030	.026	11.30
Gloucester Sandy Loam	Middleboro, Mass.	0.93	.016	.013	9.12
Peat	Milwaukee, Wis.	0.42	....	....	.....
Miami Clay Loam	Milwaukee, Wis.	0.42	.023	.019	29.55
Norfolk Fine Sandy Loam	Mobile, Alabama	1.14	.020	.017	9.74
Clay	New Orleans, La.	1.10	.017	.015	8.90
Muck	New Orleans, La.	1.92	.022	.019	6.46
Penn Silt Loam	Norristown, Pa.	0.94	.017	.013	9.03
Merriman Gravelly Sandy Loam	Norwood, Mass.	0.19	....	....	.....
Dublin Clay Loam	Oakland, Calif.	0.55	....	....	.....
Knox Silt Loam	Omaha, Nebraska	0.41	.018	....	.....
Wabash Silt Loam	Omaha, Nebraska	0.38	.015	.013	22.35
Ontario Loam	Rochester, N. Y.	0.18	.014	.016	58.00
Clay	Salt Lake City, Utah	0.30	....	....	.....
Houston Black Clay	San Antonio, Texas	1.17	.018	.016	8.94
Everett Gravelly Sandy Loam	Seattle, Washington	0.08	....	....	.....
Genesee Silt Loam	Sidney, Ohio	0.70	.030	.026	24.30
Miami Silt Loam	Springfield, Ohio	0.81	....	....	.....
Hempstead Silt Loam	St. Paul, Minn.	0.37	.033	.026	45.90
Sassafras Silt Loam	Wilmington, Del.	0.82	....	....	.....

*The pitting factor is the ratio of the maximum penetration (avg. 5 deepest) to the avg. penetration in inches per yr. The values for average penetration are obtained from the avg. losses per yr. in ounces per sq. ft.

not be treated in the same way as metal specimens, and as yet a satisfactory method of testing them has not been devised. The asphalt with which they were coated was so soft that in certain locations it became very sticky when exposed to the sun while being buried. Other specimens were slightly injured while being removed. Tests of the absorption of moisture by these specimens are in progress at the Bureau of Standards where they will be less subject to injury, and it is hoped that tests of the strength of some of the specimens can be made after they have been in the ground for a few years. It has not been possible, however, to conduct such tests in time to incorporate the results in this report.

When the pipe specimens were removed, about one-half of the sets were so marked that it was possible to tell their orientation and position with respect to the sides of the trench and to each other, and a careful study has been made of them for the purpose of determining whether there is a relation between the position of the specimens and the amount, distribution, or character of corrosion.

If the specimens were subject to stray currents, the side of each specimen facing in the direction of the flow of the stray current should show more corrosion than the opposite sides. If there was galvanic action between two specimens, two pairs of specimens in the same trench should show similar distribution with respect to the individuals of the pairs and the insides should be free from corrosion due to this cause.

Since one side of each specimen was close to the wall of the trench, any effect due to the trench wall should be apparent when the specimens are arranged on tables as they stood in the trench. If there is greater or less corrosion due to differences in the metal at the weld, or to strains in rolling or cutting, these effects should also be evident.

There appears, on the average, to be somewhat less corrosion on the inside of the pipes than on the outside. The distribution of corrosion is as irregular and, although it was not practical to measure the depth of inside pits, they appear to be about as deep as on the outside pits in most cases. In a few cases

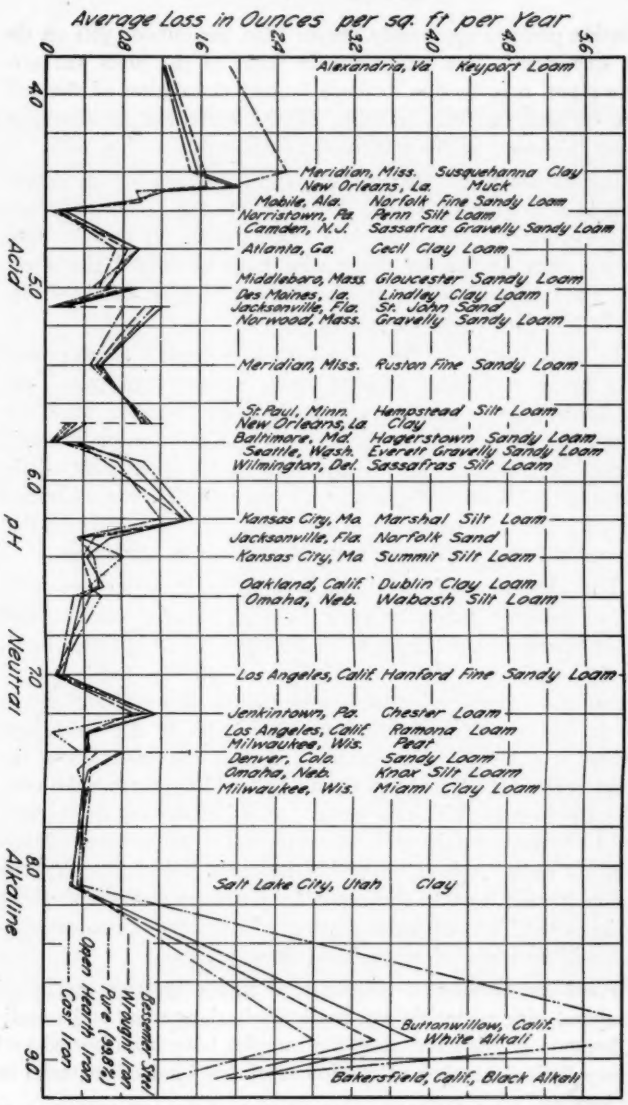


FIG. 1—CHART SHOWING COMPARISON OF CORROSION OF SPECIMENS

the inside pits are apparently deeper than the outside pits on the same specimen. This difference, in favor of the inner surfaces of the pipes, may be due to more limited circulation of the soil, water or oxygen, less diffusion of the corrosion products, or greater thickness of the millscale on the inside.

It does not seem practical to present the data on the examination in a brief way, which would enable the readers to draw their own conclusions as to their significance. It may be said, however, that so far, of those who have examined the specimens, none has offered a satisfactory explanation of the irregular distribution of the corrosion.

In most instances the specimens were buried from several blocks to several miles from a street railway system. Tests were made for stray earth currents in such places as were suspected and care taken to avoid places where stray currents might influence the results. There is nothing in the appearance of the specimens to indicate effects of stray currents. They were buried one foot apart, and both theory and laboratory tests indicate that there should be no galvanic action between the specimens.

The character of the pitting in some localities seems to point to galvanic action between the pipe material and the mill scale at points where the latter was broken, while in other localities the specimens show no evidence of pitting, but a nearly uniform loss of millscale, due apparently to chemical action. In some instances the maximum corrosion is along the weld, and in others it is on the side opposite. A few specimens show the deepest corrosion adjacent to the asphalt which protects the ends of the specimens. This may appear at either the top or the bottom of samples, rarely at both ends of the same pipe. Many specimens show serious corrosion near the middle, with little or no corrosion next to the asphalt. It thus appears that there may be several causes for corrosion and that additional experiments will be required to evaluate these causes.

Final conclusions at this time as to the relative merits of the several pipe materials are particularly dangerous and unreliable because of the short time the samples have been buried and the very limited number of specimens of one kind of material in each locality.

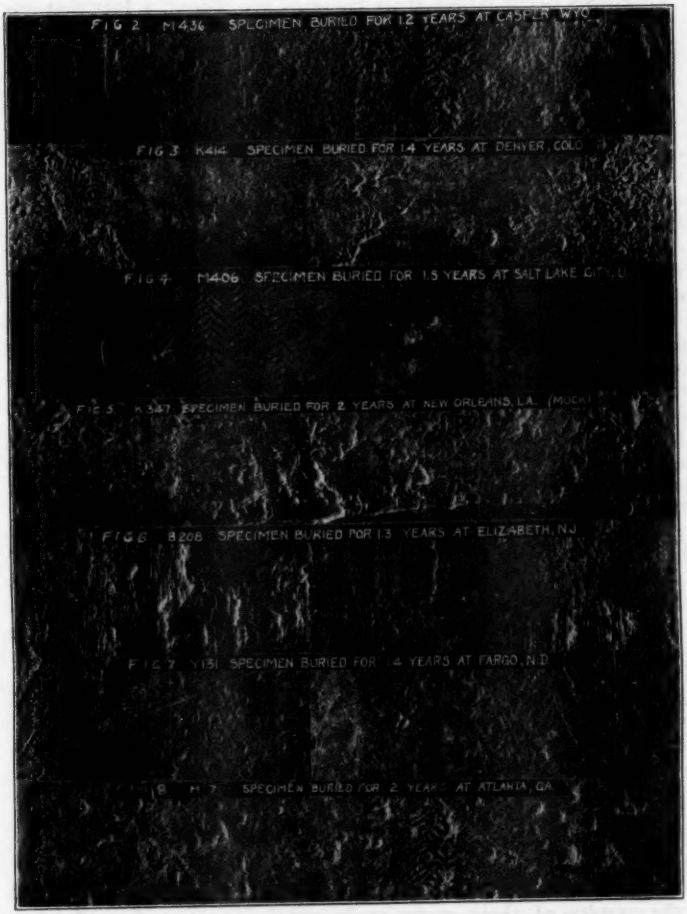


FIG 2 M436 SPECIMEN BURIED FOR 12 YEARS AT CASPER, WYO.
FIG 3 K414 SPECIMEN BURIED FOR 14 YEARS AT DENVER, COLO.
FIG 4 M406 SPECIMEN BURIED FOR 15 YEARS AT SALT LAKE CITY, U.
FIG 5 K547 SPECIMEN BURIED FOR 2 YEARS AT NEW ORLEANS, LA. (MUCK)
FIG 6 B208 SPECIMEN BURIED FOR 13 YEARS AT ELIZABETH, N.J.
FIG 7 Y131 SPECIMEN BURIED FOR 4 YEARS AT FARGO, N.D.
SPECIMEN BURIED FOR 2 YEARS AT ATLANTA, GA.

FIG. 2—SHOWING VARIATION IN PITTING OF SPECIMENS

The chief conclusions that may be reached at this time are: that rapid pitting of lead, wrought iron, cast iron, and steel, may sometimes occur where stray currents are absent, a fact that has often been disputed; that there apparently are several causes of soil corrosion; and, that in certain soils serious corrosion of wrought iron, cast iron and steel occurs within two years. Rapid pitting of lead also occurred in several cases, but in fewer cases than in the ferrous materials. In so far as the conclusion may be warranted from short time tests, the results indicate that no one of the commonly used pipe materials tested is generally superior to the others under all soil conditions. On the other hand, the tests seem to show that the pipe material best suited to one soil condition may give a relatively poor showing under a different soil condition. In other words, the soil conditions must be taken into account if the best selection of pipe material it to be made. We wish to emphasize the tentative character of this deduction pending later study of specimens subject to longer exposure. It is hoped that later results of the investigation will bring out the causes for the corrosion observed; permit the predetermination of corrosiveness of soils; and suggest a satisfactory means of prolonging the life of pipe lines.

Those interested are invited to examine the specimens thus far removed from the ground. Investigators are urged to keep the Bureau of Standards in touch with their work, to co-ordinate it with this investigation when possible, and to offer suggestions as to additional work or interpretations of results.

The outline referred to in the introductory paragraph includes a list of organizations co-operating in this investigation. To all who co-operated in the investigation the Bureau of Standards wishes to express its appreciation of the very generous and hearty responses received to requests for material and assistance, without which the investigation could not have been undertaken.

The next removal of specimens will take place in 1926 and the results of their study made public as soon thereafter as practicable.

Discussion—Corrosion of Ferrous Metals

H. Y. CARSON: The Bureau is spending a large sum of money to collect these data and the A. F. A. is to be greatly congratulated on having this report by the Bureau. I hope that it will stimulate further interest in the Bureau's work. They open the way for anyone who is really interested in the corrosion of new products, to supply them with specimens, which they will bury and test. In order to get a true lot of data on these new products they are willing to go to further expense in burying the specimens and comparing them over a period of about 15 or 20 years.

Locations were selected by the Bureau with the idea of representing about all the different types of soil which could be found. The soil found in Meridian, Mississippi, does not necessarily represent the average soil in Meridian, Mississippi, but it does represent a certain type of soil which was located there and is difficult to find, we will say, in California. The net results therefore of the tests after they are through with them won't necessarily represent the average condition which was obtained in that particular location, but it will represent the average condition which will obtain with that particular type of soil.

After the specimens were in approximately one year, some of them two years, they dug up one group. They buried these with certain groups which were marked off and they put all of the different types of materials in each group. The idea was to dig a group up at certain intervals and not disturb the other specimens. It was decided by the Bureau that it would be a mistake to dig up a specimen and clean it and then put it back under test conditions, because you disturb the physical characteristics of the specimen when you do that, and therefore it would be better to increase the number of specimens about twenty times, then dig up one group each year. In that way they could leave the others undisturbed year by year, and finally get a direct comparison between them, which will give a history over a period of 15 or 20 years.

The interesting thing that has been discovered about some of the pipe that has been buried is that in certain soils the corrosion proceeds in one particular way on all the specimens. For instance, the material at Denver, Colorado, after 1.4 years showed a peculiar action which ran along the surface of the pipe, as if a worm had crawled along the surface, eating the material. This pitting action was typical, that is, typical of all the specimens: Iron, steel, cast iron, and everything else that was buried in that particular location.

Report of Committee on Heat-Treatment of Ferrous Castings

To the Members of the American Foundrymen's Association:

Your committee on the heat-treatment of ferrous castings reports that its activities during the past year have been restricted to co-operation with committees of the American Society for Testing Materials that deal with problems involved in the heat-treatment of steel, malleable iron, and gray iron castings. It was chiefly for the purpose of establishing proper co-operation between the A. S. T. M. and the A. F. A. that our committee was organized as it is today. This committee is divided into three sections—one for steel, one for malleable iron, and one for gray iron castings—and the arrangement is such that the chairman of each of these sections is the A. F. A.'s representative on the corresponding A. S. T. M. sub-committee; and that the chairman of the A. F. A. committee proper is the A. F. A.'s representative on A. S. T. M. Committee A-4, which is the parent committee to which the sub-committees of the A. S. T. M. report.

The active work of A. S. T. M. Committee A-4 since the last convention of the A. F. A. has been restricted to the consideration of the recommendations of its Sub-Committee II on Steel Castings, which involved revisions in the recommended practice for the heat treatment of steel castings. These revisions, after approval by A. S. T. M. Committee A-4, on which your committee is represented, were submitted to the A. S. T. M. Convention in June, 1924, and have been adopted by the Testing Society as standard. Description of this revised recommended practice is attached hereto.

It may be of interest to mention that at meetings of sub-committees of A. S. T. M. Committee A-1 on Steel there have been presented during the past year, recommendations to develop for subsequent use as standards, heat treatment proced-

ures for alloy steel castings. Nothing more than preliminary consideration has been given these suggested to date.

Your committee will be pleased to receive from any member of the Association suggestions and data relating to the activities of any of its sections. Communications should be addressed, if regarding malleable iron, to Enrique Touceda, 943 Broadway, Albany, N. Y.; if regarding gray iron, to J. Fletcher Harper, Allis-Chalmers Manufacturing Co., Milwaukee, Wis.; and if regarding steel, to R. A. Bull, 541 Diversey Pkwy., Chicago, Illinois.

Respectfully submitted,

J. FLETCHER HARPER, *Chairman*
Gray Iron Section

ENRIQUE TOUCEDA, *Chairman*
Malleable Iron Section

R. A. BULL, *Chairman*
Steel Section and of Committee

Appendix—A. S. T. M. Recommended Practice

RECOMMENDED PRACTICE FOR HEAT TREATMENT OF CARBON STEEL CASTINGS

Serial Designation A36-24 Adopted, 1914; Revised 1924

Scope.

1. This recommended practice is intended solely for guidance, and is not to be construed as entering in any manner into specifications of the American Society for Testing Materials.

Types of Treatment.

2. This recommended practice covers:
   a.—Annealing.
   b.—Normalizing.
   c.—Normalizing followed by a reheating.
   d.—Quenching followed by a reheating.

Cooling After Pouring.

3. After pouring, the castings should be allowed to cool in the sand to a temperature below the critical range.

Cleaning.

4. The castings should be sufficiently cleaned of adhering sand before heat treatment to insure thorough and uniform heating.

Temperature When Above Upper Critical Point.

5. The temperature recommended when treatment above the

upper critical point is desired should vary with the carbon content approximately as follows:

Carbon, per cent.	Temperature
Up to 0.40	900° C. (1650° F.)
0.40 to 0.60	850° C. (1560° F.)
Above 0.60	830° C. (1525° F.)

Control of Temperatures.

6. The use of pyrometers (preferably recording) is recommended. Pyrometers should be checked frequently against a standard. Every precaution should be taken to procure due assurance that the castings throughout the furnace reach the required temperature.

Heating.

7. After cooling as indicated in Section 3, the castings should then be heated slowly and uniformly to the desired temperature. Sufficient time should be allowed for the heat to accomplish the desired structural transformations throughout the mass of the castings. For these reasons it is necessary that each furnace containing castings be held for a prolonged period at the desired temperature after the castings have attained that temperature. It is recommended that this prolonged period should not be less than 60 minutes for each inch of thickness of the thickest casting segment in the charge.

Annealing.

8. To anneal castings properly they should be heated as described in Section 7 to one of the temperatures shown in Section 5. They should then be slowly cooled in the furnace until they reach a faint red color, after which the cooling may be continued in air.

Normalizing.

9. To secure finer structure (with probably less ductility than can be obtained by annealing as described in Section 8) castings should be heated as described in Section 7 to one of the temperatures given in Section 5, and cooled in still air.

Normalizing Followed by a Reheating.

10. To secure fine structure, accompained by great ductility, normalizing as described in Section 9 should be followed by reheating and subsequent cooling. In this reheating, the castings may be kept for a short time just above the lower critical point or they may be kept for several hours at a suitable temperature below the critical range. After this reheating the castings should be cooled slowly in the furnace until they reach a faint red color (provided they reach this color in the reheating), after which the cooling may be continued in air.

Quenching Followed by a Reheating.

11. To secure maximum refinement of the structure coupled with the greatest possible combination of strength and toughness, castings should be heated as described in Section 7 to one of the temperatures given in Section 5, and quenched in water or oil. They should then be reheated. In this reheating, the castings may be kept for a short time just above the lower critical point or they may be kept for several hours at a suitable temperature below the critical range. After this reheating the castings should be cooled slowly in the furnace until they reach a faint red color (provided that color was reached in

the reheating operation), after which the cooling may be continued in air.

Precautions for Quenching.

12a. Certain castings which from their mass or design would crack on quenching if kept in the water or oil until completely cold may be safely treated by removing them from the quenching bath when they have reached a black heat, immediately charging them into a furnace heated to approximately the same temperature as the castings, and reheating them as described in Section 11.

12b. The advisability of attempting to quench and reheat any given casting must be considered with judgment in the light of experience; and to attempt to apply this method of heat treatment without taking the precautions demanded by the shape, size, and sections of each individual casting can only result in the loss of many castings through the development of cracks either in quenching, in reheating, or at some later time.

Discussion—Report of Committee on Heat Treatment of Ferrous Castings

DAVID EVANS: While having given this only cursory thought, it just occurred to me for the moment, wouldn't it be advisable to differentiate between annealing and heat treatment? There is a rapidly increasing demand for alloy steels, their use is becoming more general all the time, and many of these special alloy steels require more than the simple annealing. Annealing is a term which has been thoroughly understood, and which it is customary to use. I believe that every steel casting nowadays, practically all steel castings, are annealed, while heat treatment would indicate something in addition to the simple annealing, heating and quenching and annealing after that, as applied to alloy steel castings. I merely, just on the spur of the moment, offer this suggestion for the consideration of this committee. And I want also to take advantage of the opportunity to thank the committee and Mr. Bull for their numerous contributions to steel foundry practice.

CHAIRMAN J. H. HALL: I think I can answer that myself quite quickly and easily.

In the American Society for Testing Materials we found a great objection on the part of the producers to recommend the practice at all. They didn't want it . After we got through we found a great objection to drawing any recommended practice which would allow you to do anything but anneal. They didn't want us to do any normalizing, following by reheating; they wanted to hold the steel maker down to plain, old-fashioned annealing. We had a long, long fight to be allowed to call our specifications "heat treatment," so that we could include heat treatments. They wanted to call it annealing, and then they had us by the ear, we couldn't describe any heat treatment. That is one reason.

The other reason is that the committee, the joint committee appointed by the three societies to draw up terms describing heat treatment, the American Society for Testing Materials, the S. A. E., and the American Society for Steel Treating, tried for two years to agree on terms describing heat treatment practices and annealing practices, and they couldn't even agree on what was the proper definition of annealing. They haven't yet. One man called annealing this, another man called it something entirely different; one man said, "This is annealing"; the other said, "No, I won't allow that to be called annealing for a moment." They couldn't agree and they have had to agree to disagree on what even annealing is. But we did get as far as being allowed to say that heat treatment applies to any process of taking a casting after it is cooled in the sand and putting heat on it and it included annealing and heat treatment and everything else; that is why we called it heat treatment.

Report of Committee on Non-Ferrous Castings

To the Members of the American Foundrymen's Association:

Your Chairman and Mr. R. J. Anderson and Mr. Fred L. Wolf have taken an active part during the past year in the work of Committee B-2 on Non-Ferrous Metals and Alloys of the A. S. T. M. The portions of the work of most interest to the A. F. A. are the following:

Sub-Committee III on Sand Cast Metals and Alloys.

Considerable work was done upon a modified Keel-Block type test piece with web gates running to the threaded ends only. This test bar proved satisfactory for red brasses, but unsatisfactory for high shrinkage alloys like manganese bronze. Its weight, amounting to about 30 to 40 pounds, is also a practical objection to this type of bar. Further work is being done on modified forms of this same bar and also on a type of bar cast vertically with pencil gates. Practical suggestions from any members of the A. F. A. will be welcomed by the Chairman.

A further suggestion for a standard test piece has been made by L. W. Olson, President of the A. F. A., namely, to make a standard test piece in a permanent iron mold similar to that used by the Holley Carburetor Co. Such a test piece would be representative of the metal only and it would be necessary to have another test piece to represent castings of varying cross-sections or to test the castings themselves to ascertain the characteristics of the same metal when cast in varying cross-sections.

Standard specifications for manganese bronze sand castings and for ingots, were also revised by the committee.

Sub-Committee VIII on Aluminum Alloys.

The present list of aluminum alloys has been revised and brought up to date. A report has been prepared on "High Strength Light Alloys" and a similar statement is in preparation on magnesium alloys.

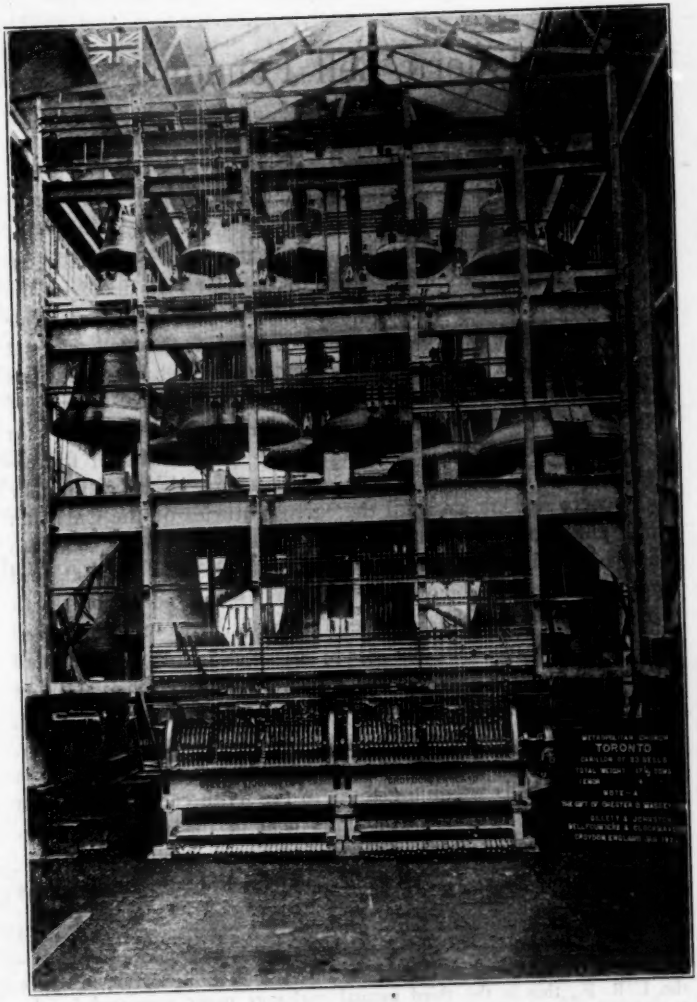
Sub-Committee XII on Metallic Fluxes and Deoxidizers.

Tentative specifications on phosphor tin, phosphor copper and silicon copper have been prepared.

In the opinion of the chairman, the A. F. A. Committee on Non-Ferrous Castings could well undertake some lines of work that have not been touched upon by the A. S. T. M.; for instance, permanent mold castings, centrifugal castings and die-castings. Suggestions from A. F. A. members as to the desirability of work along these lines or other lines, will be gladly received by our committee.

Respectfully submitted,

J. L. JONES, *Chairman*



A CARILLON OF TWENTY-THREE BELLS

Modern Bell Founding

By Wesley Lambert and G. Hall, London, England

Section I—Historical Notes on Bells

How the bell originated, or by whom it was actually invented, is lost in antiquity. Josephus tells of bells fixed on the golden roof of Solomon's Temple to "keep the birds from alighting thereon," which bells, presumably, were very small and not much larger than the present day hand-bell. Suetonius mentions that Augustus caused a bell to be hung before the Temple of Jupiter. It is recorded that Julius Caeser on landing in Britain heard the tinkling of the bells upon the spear shafts of the assembled warriors. Large bells—such as one is now familiar with—were not known until the early centuries of the Christian era. The introduction of the large bell has been ascribed to Italy, both Bishop Paulinus of Nola, about the year 400, and Pope Sabinianus, about the year 600, being accredited with effecting its introduction. The Venerable Bede brought a bell from Italy to place in the Abbey of Wearmouth in 608, and mention is made of a bell being in use at Whitby Abbey at about the same time. S. Ethelwold, Bishop of Winchester, 923-984, was responsible for the casting of the bells for Abingdon Abbey. Ingulphus, the Chronicler of Croyland Abbey, mentions that a peal of seven bells was hung there in the tenth century, and that "there was not such a harmonious peal in the whole of England,"—a statement which implies that "rings of bells" were common at that time. Of early bell-founders, London can claim as

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This paper is one of a series of foundry problems being exchanged between the Institute of British Foundrymen and the American Foundrymen's Association. Initiated in 1921 with the first A. F. A. paper before the I. B. F., this is the third annual exchange paper presented by the British organization. Mr. Lambert is a member of the Institute of British Foundrymen and is connected with the firm of J. Stone and Company, Ltd., of Deptford, London.

citizen, Alwoldus, a *"campanarius"* (bell-founder) as early as 1150, and in the reign of Richard I of England the Guild of Saddlers was granted the privilege of ringing bi-weekly the bells of the Priory of S. Martins-le-Grand; the Priory being entitled to claim the sum of 8d for "ringing" at the funeral of deceased members of the Guild.

An ancient bell having the date 1133 *cast* upon it was recovered from a pond at Preston in 1897. It is stated on good authority that the bell at Fontenville, Bayeux, in France, bearing the date 1202, has the distinction of having been in continuous use for the greatest number of years. In England, what is believed to be the earliest church bell is to be found in St. Chad's Church, Claughton in Lonsdale, Lancaster; it bears the date 1296, and although a small bell, it has done duty for over 600 years. Bells of large size were founded as early as the twelfth century, about which period a tenor bell was added to the "ring" at Canterbury Cathedral; the complete "ring of bells" requiring thirty-two men as ringers. This bell was, however, surpassed by one cast in 1316 which weighed 3½ tons. John of York was a noted bell-founder about the middle of the 14th century; at Sproston in Leicestershire there is a bell inscribed (in Latin) "John of York made me in honour of the Blessed Mary."

The following list includes the best known English bells:—

Name	Place	Weight Tons
Great Paul	St. Paul's Cathedral	16-17
Big Ben	Westminster	13-14
Great Peter	York Minster	12-13
Great John of Beverley	Beverley Minster	7- 8
Great Peter	Exeter Cathedral	6- 7
Great Tom	Oxford	6- 8
Great Tom	Lincoln Cathedral	4- 5

Westminster Town Hall, London, possessed a bell famous for its connection with a story told as happening in the reign of William III, of a sentinel at Windsor Castle, who was accused of sleeping at his post. He defended himself by stating that he was not asleep, but that he was placing his ear to the ground in order to hear the Westminster clock strike at midnight, and that he not only heard it, but that it struck 13 instead of 12. It was subsequently attested that the clock did, on that

occasion, actually strike 13, and the soldier was acquitted.

The bell of Lincoln's Inn Chapel, London, formed part of the spoils at the capture of the City of Cadiz by Lord Effingham of "Good Queen Bess' days", and was brought to England by the Earl of Essex, favourite of that Queen, in 1596. Notwithstanding the general discontinuance of the ringing of the Curfew at the end of the 16th century, the bell at Lincoln's Inn Chapel continued to be rung and the custom is still maintained, the Curfew being rung nightly at 9 p. m. The bell is tolled 50 times, a pause being observed after the first and before the last strokes.

The great Westminster clock-bell "Big Ben" was so named after Sir Benjamin Hall, who was in office as the Parliamentary First Commissioner of Works at the time the bell was cast. The original bell was made by Messrs. Warner, of Stockton-on-Tees, but it developed a crack during its public exhibition at the foot of the clock tower, and the bell was recast by Messrs. Mears, of Whitechapel, London; it weighs 13½ tons.

The known largest bell in existence is the great bell of the Kremlin, "The Monarch of Moscow." The value of the metal used in the casting alone was said to exceed £66,000 sterling; the casting is now defective, a considerable piece having been broken away from the side owing to a fall in 1737. The table on the following page is a comparison of the estimated weights of the heaviest bells of which records are available.

When large bells were required in the early days they were cast locally ready to be placed in the belfry or bell-tower. The bells of York Minster were moulded and cast within the Minster walls; one reason, and the principal reason for so doing, was the absence in those days of good country roads, and the difficulty of road transport of very heavy bells was therefore practically insurmountable.

Bell founding was for centuries a very slow process. The appliances for "striking-up" and lifting the mold, and also the furnaces for melting the metal were all very crude. The old-time bell-founder, however, was an expert craftsman among his fellow-men, and speaking generally, the craft was handed down from father to son. "Robert Alton made me 1633." Robert

Table 1

WEIGHTS OF LARGEST BELLS

Place	Tons	Diameter
Moscow	220	22′ 8″
Trotzkoi-Russia	171	
Moscow	110	18′ 0″
Mandahay-Burmah	87	18′ 0″
Moscow-S. Ivan's Ch.	57	18′ 0″
Pekin	53	14′ 6″
Novgorod	31	
Moscow	28½	
Cologne Cathedral	25½	11′ 3″
Nanking	22	
Lisbon Cathedral	21	
Kioto-Japan	20	10′ 0″
Paris (Montmartre)	18½	9′ 11½″
Vienna	17¾	
London (Great Paul)	16¼	9′ 6″
Rouen	16	

NOTE—Authorities differ considerably in the weights of some of the bells included in the list.

Alton, upon receiving an order to make a bell or a peal of bells for a certain church would proceed to erect his temporary foundry near the church itself. He would commence actual operations in the foundry by building up a core for the mold in a hole dug in the ground. The base-plate was either of timber or of iron; the core-spindle being mounted in a socket set in the center of the base-plate. Having built the core with bricks and clay by the aid of a strickle, the core was dried by a charcoal fire. A second strickle was then placed into position and a thickness of sand or loam struck on the core, conforming to the finished shape of the outside of the bell to be cast; any inscription being formed in wax and carefully fastened to the sand or loam, which wax in the drying process melted away, leaving the imprint of the letters in the cope or outer case of the mold. The outer case of the mold was in its turn subjected to the process of drying. The cope was formed of brickwork and loam by building-up the same on a large iron ring until the core and bell-thickness was completely enveloped. After a period of drying this outer part was lifted, then thoroughly dried and finally washed with a charcoal-and-clay wash to give it the requisite smooth surface. The bell-thickness was then removed from the core, and when the complete mold was re-assembled, a space was left between the cope and the core, of a shape and

thickness corresponding to that of the bell required. The cope or outer case having been put back into position, the complete mold was rammed tightly in the earth, and, maybe, wedged in with timber to support any strain set up in the casting operation. Simultaneously with the molding operations a furnace had to be erected. The furnace of Robert Alton's day was on

FIG. 1—OLD TIME TUNING OF BELLS

much the same lines as the reverberatory furnace of today, but on account of its temporary character somewhat more crudely built than the furnaces to be found in modern bell foundries. Charcoal was the fuel used for melting the bell-metal. A hole at the side of the furnace served as a tapping-hole, communica-

tion being made between the furnace and the mold by a sloping channel. Great care must have been exercised in respect of both the metal and the temperature of casting. Many old bells cast as long ago as the 15th and 16th century are made of much better metal than some of the bells cast within the last few decades. The old bell-founders therefore, had much to their credit as skilled craftsmen, and considering the difficulties to be surmounted in the exercise of their craft, they must have been men of strong will and courage. Robert Alton, having cast a bell and allowed it to "cool off," would then proceed to strip it from the mold and to "clean it up a bit" with the object of making as presentable a bell as possible. He would then sound it carefully in order to observe whether it yielded a correct note, a musician with a violin sometimes being engaged to assist in the tuning; chipping being resorted to until the correct note was obtained.

Neither the contour of the bell, nor the art of bell-founding has changed, except in minor respect, through many centuries; useful knowledge, however, has been gleaned from the study of the products of the old bell-founders. In early days bells were not "rung up," as they are now, but were simply "chimed"—i. e., sounded as a result of swinging the bell just sufficiently to strike the suspended clapper, or the bell remaining stationary, the clapper being swung; the latter a most deplorable practice, and a custom which accounted for many cracked bells. That this was realized as early as the sixteenth century is shown by the Churchwarden's accounts of St. Lawrence, Reading, for 1584, in which an entry appears as follows:—

"Whereas there was, through the slouthfulness of the sextun in time past a kind of tolling ye bell by ye clapper rope; ye was now forbidden and taken away."

When "rung up," as is now the practice, the bell swings through a little more than a complete circle, and after each stroke rests in an inverted position, that is, mouth uppermost against a stay, until "the rope" is again pulled, when it swings down, strikes the clapper, and reverts again to an inverted position on the other side.

The inscriptions and markings found on old bells are often

quaint and sometimes very peculiar. Occasionally, here and there, a bell of freakish shape has been hung, and such a bell usually possesses a somewhat displeasing tone. There is a superstition that bells shiver and quake on the occasion of a crime or disaster. The bells of Canterbury are said to have rung without human agency what time Archbishop Beckett was mur-

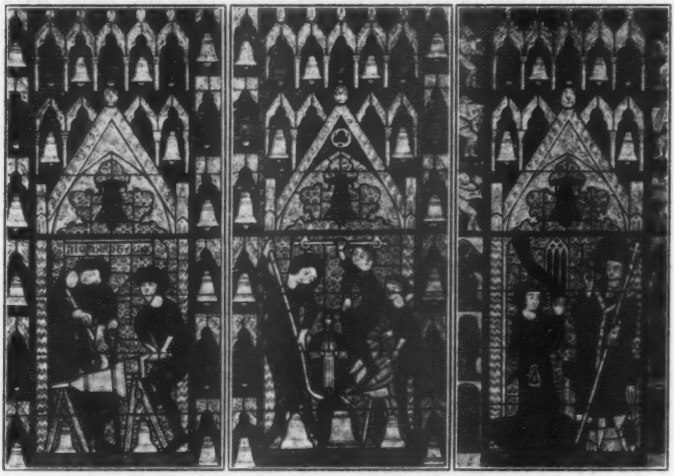

FIG. 2—BELL-FOUNDERS' WINDOW, YORK MINSTER

dered, as also did the bells of Lincoln at the burial of St. Hugh, the Lincoln martyr:—

"A' the bells o' Merrie Lincoln
Without men's hands woe rung;
And a' the books o' Merrie Lincoln
Were read without men's tongue;
And ne'er was sich a burial
Sin Adam's days begun."

It is placed on record that high festival was often observed before church-bells were hung in the belfry. The casting was used as a receptacle of liquid refreshment for the enjoyment of the assembled parishioners!

York possesses two interesting memorials having reference

to the art of bell-founding. The one is an ancient cross erected to the memory of an unknown craftsman. On one side of the cross is a brazier or furnace, and on the other is the figure of an antique bell. The second memorial takes the form of a stained-glass window in the nave of the Minster, and is known as the "Bell-Founders' Window." Several of the operations involved in casting a bell are represented. The mold for the bell is shown in vertical section, and the metal is seen running into the mold. The man (over life size) is teeming the metal from a crucible; an assistant is holding back the dross. The window was presented to York Minster in 1320 by Richard Tunnock, Bailiff of the City.

* * * *

"Lambert made me weake, not fit to ring,
But Bartlet amongst the rest hath made me sing."

(Inscription on an old bell at Richmond, Surrey.)

W. L.

Section II—Bell Founding

Modern practice in the art of founding large bells follows more or less on the lines adopted by the old bell-founders, but whereas in times gone by it was firmly imagined that bell-founding was one of those crafts the mysteries of which were handed down from father to son only, the mysteries have vanished, and the art of bell-founding is one well within the scope of experienced loam moulders, irrespective of parental ancestry. Nevertheless, as is only to be expected, large bells of good tone bearing long cast-on inscriptions and much artistic ornamental work, are most often the product of firms specializing in this class of foundry work. Naturally, the modern bell-founder, not having to face any great difficulty regarding the transport of his heavy castings, establishes a well equipped foundry replete with a suitable range of equipment and accessories to meet the requirements of his various customers. In addition, a designing department, pattern shop, and machine shops are also included

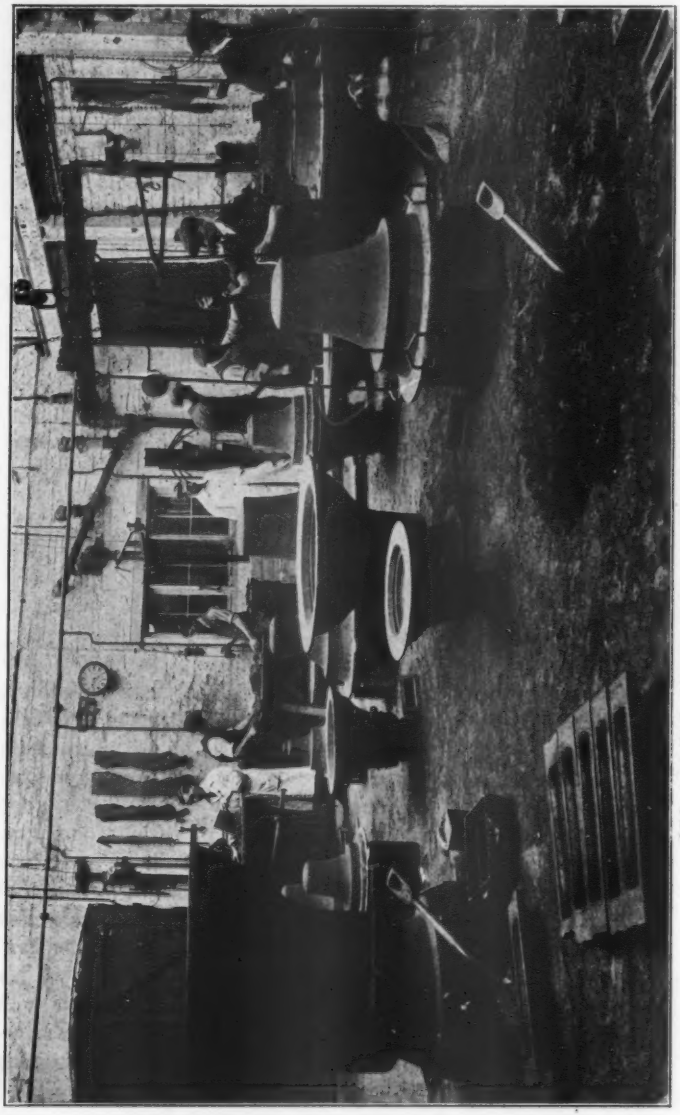

FIG. 3—BELL FOUNDING. PREPARING THE MOLDS

in the modern bell-founding works. With the foregoing facilities for output, it is customary, whenever possible, to cast a complete peal of church bells from one and the same cast of metal, use being made of one or more ladles to hold the metal when the furnace or furnaces are tapped. Should the weight of metal to be melted for the complete "ring of bells" exceed the capacity of the furnace, as sometimes happens, the "cast" must be divided, care being taken to ensure that the metal of subsequent casts approximates in composition as closely as possible to that of the previous cast.

Working-drawings, together with an estimate of the weight of each bell in the "as-cast" condition, are prepared in the designing department and passed on to the patternmaker. The working drawings are usually made full-size, thus obviating any error in setting out the curves of the bell, these latter being an all important factor in determining the thickness and subsequent tonal results of the finished bell. The working drawings are often prepared on thin paper, thus enabling the patternmaker, by placing carbon sheets between the timber and the drawing, to trace the lines direct upon the wood by means of a stylus. The timber used by the patternmaker for the strickle-board, etc., must be of a hard nonporous character and well-seasoned, otherwise, owing to distortion of the wood, unequal thickness and distorted shapes will be evident in the castings, the rectifying of which defects is not only costly but requires considerable skill on the part of the mechanic whose job it is to prepare the bell for tuning. Two strickle-boards are required for each bell-mold; an outside-board for striking-up the exterior, and an inside-board for striking-up the core. Both boards must have well finished sharp edges, and notches are cut in each board to indicate the positions at which sizes are determined by the aid of size sticks. These latter are supplied by the patternmaker, and must be preserved from injury when in use. The strickle-boards and other parts made by the patternmaker are checked by a draughtsman before being passed on to the foundry. In general practice it is now usual for the mold for the heaviest bell—known as the tenor bell—to be commenced in advance of the others, and the subsequent molds are proceeded with in order of weight of bell to be cast.

The reason for this is obvious, as if all the bells are to be cast from one charge of metal, the heavier the bell to be cast the longer the period required to prepare and dry the mold in order to have all ready for filling on the same day.

The actual operation of molding proceeds on the following lines. Use is made of a heavy baseplate—permanently fixed on

FIG. 4—CORE FOR LARGE BELL

a concrete bed on the foundry floor—having three raised sides, which are machined level, upon which stands are placed serving as stools for the "bell-case." In the center of the baseplate is a conical pin upon which the bottom end of the spindle rests, the top end of the spindle fits over a similar pin which is fixed in a

robust cast-iron bracket projecting from the foundry wall or a column. The spindle is made of round steel, and is machined over the entire length. The projecting bracket is mounted on a pivotal pin, and by this means it can be swung away from the mold on the completion of the molding operations. Attached to the spindle is a bar which serves to carry the strickle boards; these latter are bolted into the desired position. The striking-up of the mold portion forming the outside of the bell surface differs somewhat from the usual practice followed in ordinary loam molding, a cast iron "bell-case" casting, not unlike a bell in shape, being employed in lieu of the usual brickwork and binders. These "cases" are usually about six inches larger in internal diameter than the external diameter of the bell to be molded, thus allowing for a generous thickness of loam, etc., in the mold proper. The "bell-case" castings are provided with trunnions for lifting and upending purposes. These trunnions are essential, as the portion of the bell-mold in question is molded the reverse way up, that is to say mouth upwards, and it is reversed in the completed mold as assembled for casting.

The "case" is placed on the three stands aforementioned, and carefully squared and lined-up to the appropriate strickle-board which is in position on the arm of the spindle; loam cakes, previously molded and thoroughly dried, are cemented with a clay wash to the inside of the case, and the first rough coat of loam is plastered on over the whole surface of the cakes, use being made of the strickle-board and the necessary care being taken to leave a sufficient space for a second or final coat. The "case" is then placed in the drying-stove, where it remains until the mold has become thoroughly dried. In like manner all the other mold "cases" for the complete set of bells to be cast are prepared and stoved. The drying-stove equipment usually includes various sizes of trolleys or carriages, and each "case" is placed upon a separate carriage, due regard being paid to the position of each case in the stove, and also economy of floor space, in order to utilize to the best advantage the full stove capacity. As soon as the rough loam coating of a mold is thoroughly dry, the "case" is returned to the base-plate and again levelled and set as accurately as possible to the strickle-board, measurements are checked,

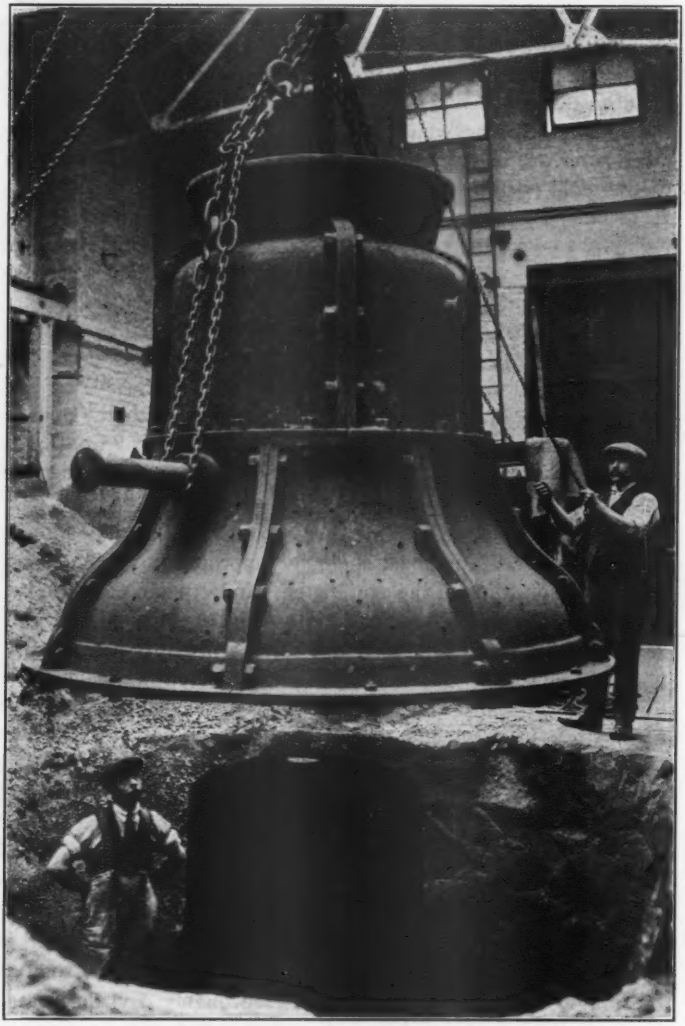

FIG. 5—ASSEMBLING THE MOLD FOR A LARGE BELL

and the final coat of loam is applied. The loam used for this final coat must be well ground and of a very fine and smooth texture, fairly free from clay; cowhair is sometimes used in admixture with the loam to ensure the necessary binding. The final coating of loam as applied to the mold must be as thin as practicable, and should rarely exceed three-eighths of an inch in thickness, otherwise contraction cracks will develop in the mold during the final drying, and unsightly "veins" will be found on the surface of the subsequent casting from the mold; such "veins" may seriously detract from the appearance of the lettering and ornamental work with which many bells are embellished. The final coat of loam having been applied to the mold and care-

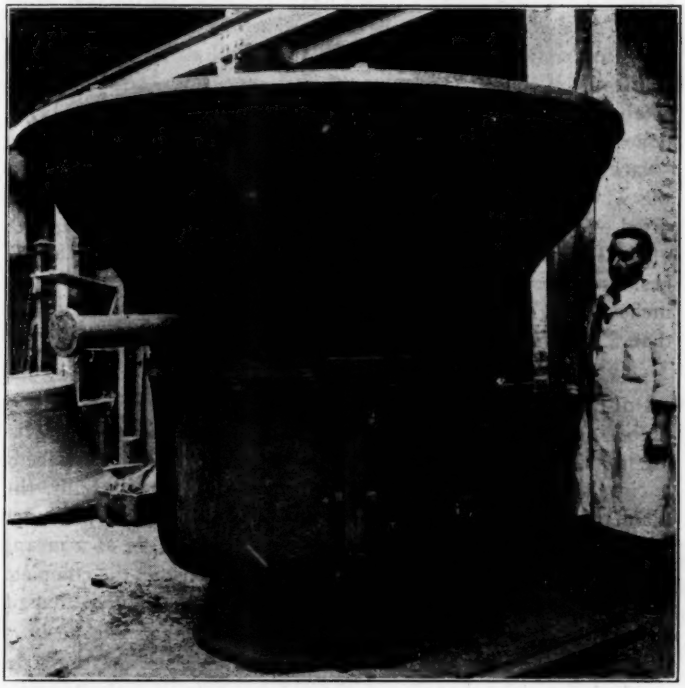

FIG. 6—BUILDING UP BELL-CASING FOR LARGE BELL

fully strickled, the mold in its "bell-case" is returned to the drying-stove and very thoroughly dried, great care being taken that the mold is not scorched or burnt during this operation. The mold is then taken from the stove, and when quite cold, is checked for size by an experienced molder, who, when he has satisfied himself that the mold is correct, proceeds to apply a wash of good blacking to the surface of the loam. A satisfactory blacking-mixture for this purpose is made up by an intimate admixture of 60 per cent of charcoal-blacking, 30 per cent of plumbago, and 10 per cent of china-clay.

After careful sleeking of the surface of the "blacking" to a very smooth finish, the mold is lined and set out to receive any ornaments or inscriptions which have to appear on the bell when cast. As many as five to six hundred letters appear in some of these inscriptions, and as many as two hundred letters are quite common. Each letter or numeral is stamped into the mold separately, this work, including the stamping of the ornaments, being done while the mold face is still soft after the application of the "blacking-wash." The inscription is carefully checked as soon as the whole is completed, and if found to be correct, the mold is dried-off by the heat from a small brazier placed under the mouth of the "bell-case." Fig. 7 shows a bell bearing nearly 1000 letters besides ornamental work cast on the surface; the letters are 1¼ inches and ¾ inch, and stand out in relief about ⅛ inch; more than 2500 letters appear on the complete set of eight bells.

At the same time that one gang of molders is preparing the set of "cases" or outer parts of the bell molds, another gang is preparing the cores or inside parts. The strickle-arm for working-up this part of the mold is similar to that previously described; a circular base-plate is used upon which the core is built, the diameter of the plate corresponding to the diameter of the outer flange of the bell-case. Bolt-holes in each part serve as a means of subsequently securing each part to the other when the complete mold is assembled. The strickle-board of exact shape to that of the desired interior of the finished bell, is then fixed into position on the strickle-arm, and the core is built of brick and loam in much the same way as any ordinary loam core of a similar type is commonly constructed. Should, however, the core be intended

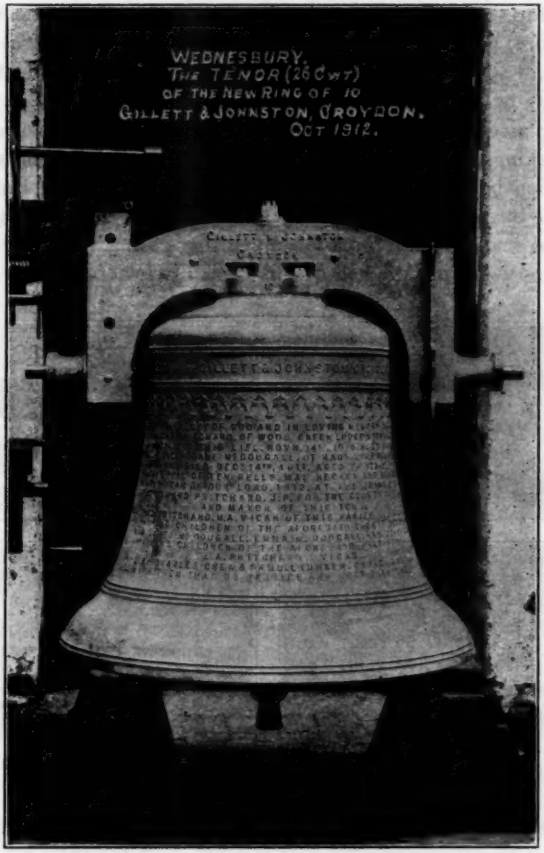

FIG. 7—BELL WITH NEARLY 1,000 LETTERS CAST ON IT

for the mold of a large bell, a "binder" of cast iron is built into the top of the core. The same practice is followed as regards the drying and final coat of loam, blacking, etc., on the core, as appertains in preparing the outer portion of the mold as previously described. Special care and attention must be given to the forming of the top of the core for the reason that bells are cast

from the top with the mouth of the bell towards the floor, and therefore, unless the top of the core is well made and free from cracks, a scab or a fracture may result, and the subsequent casting may be judged a "waster."

In assembling the completed parts of the mold no setting-out or marking-off is entailed, as is so often the case in loam molds, provision being made for this in the actual molding. Both the strickle-board for the outer "case" and for the core have a tapered seating, thus for a large bell the seating would be about 2 inches wide, and the bell-case is carefully lowered by the crane

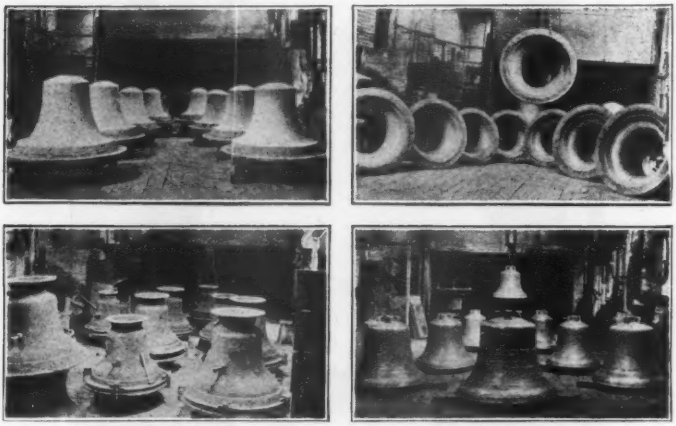

FIG. 8—VARIOUS STEPS IN BELL MOLDING

over the core until resting just above the seating, and whilst in this position the suspended part is gently and carefully rubbed by a rotary motion until when the bell-case is finally lowered a perfect joint is secured.

The mold for the largest bell of the set having been assembled and bolted, it may be sunk to a depth of a few feet into the foundry floor; a runner-box is then fitted and bolted into position. To bring the runner-boxes of each mold to about the same level one with another, provision is made for bolting a box on to a flange carried on the "bell-casing." A plug-runner is used

with a down-stem of about two inches for large bells, and a small riser or "flow" to denote when the mold is full of metal.

Modern bell-founders mostly use the reverberatory type of furnace for the melting of the bell-metal, this type of furnace ensuring better control over the mixing and the subsequent alloy, and, moreover, the whole of the metal required can be melted in one heat. The temperature of the bath of metal is ascertained from time to time by means of a pyrometer. With the exception of very large bells, all castings are removed from the molds on the day following the cast, and the core having been dislodged, the bell is brushed over with wire-brushes and is then submitted to a critical inspection, checked for size and thickness, and tested by the "tuner" as a preliminary measure before proceeding with any further work on the casting. The bell having passed this first inspection, it is fettled and cleaned up by filing, after which it is subjected to a process of cleaning by sand (or shot) blast. The casting is again inspected, and if found satisfactory the bell is passed on to the machine shop. The second inspection and passing of the casting removes any anxiety the foundryman may have had as to whether the casting was a success or a "waster"; the inspection after sand-blasting serving to discover any casting-defects of a serious character.

In general foundry practice little or no public ceremony attaches to the actual casting operations; this, however, is not always so in the bell-foundry. The occasion upon which a peal of bells is to be cast is often made a ceremonial day, and regarded as an auspicious event. One can well leave to the imagination of the reader the incongruous atmosphere in which some of the visitors who assemble in the foundry find themselves on such an occasion, and also the effect upon the nerves of both the visitors and management, if for any reason the "tapping" of the furnace is delayed long past the appointed time.

G. H.

Section III—Metallurgical Notes on Bell Metal

The metal *par excellence* for large bells is essentially an alloy of copper and tin. Large bells have been cast in other metals or alloys, as, for instance, in aluminum-bronze and in steel. Lord Grimthorpe, an eminent authority on clocks and bells, when asked his opinion of some bells cast in steel, replied: "If the object of the bells is to make the greatest noise for the least money, steel bells are very good ones, but the less you ask me to say about the quality of the noise the better." Bell-metal is a true bronze, in that it is compounded from copper and tin, the former metal being present in predominating quantity. The alloy "80 copper 20 tin," passing under the name of bell-metal, is quoted in books of reference more often than any other alloy of these two metals; whereas, it is common knowledge among those persons interested in metal for bell-founding that a fairly large departure from the 80:20 alloy is permissible without sacrificing the strength or tone of a bell. All metals are resonant when struck under favorable conditions; even lead, cast in the form of a hollow spherical segment, is stated to be very sonorous.

The first requisite of a good bell-metal is that it should be pleasingly sonorous when struck, the sound produced being of a full, rich, and pure tone. Other requisites are comparative cheapness and good casting properties. In these respects the alloys of copper and tin, i. e., the true bronzes, possess the before-mentioned qualities in a marked degree; the 80:20 alloy being a good example in a somewhat wide range of these alloys. To ensure a pure full sound from a bell it is not only necessary to employ a suitable alloy and correct proportions for the bell, but the casting itself in the selected metal must be sound, as free as possible from blemishes, slag, and oxide inclusions, and should be representative, in every respect, of the best art of the foundryman.

Nowadays, the foundryman proper has but little say in respect to either the shape or proportions of the bell to be cast, and merely acts upon instructions received from the designer. Nevertheless, he is expected to produce a casting which will result in an almost perfect musical instrument.

The range of the true bronzes which may be said to constitute the genuine bell-metal alloys suitable for the founding of large bells is represented by the difference between a tin content of 17 per cent on the one hand and 25 per cent on the other. Authentic analyses of large bells cast in by-gone days give figures well outside the range indicated, but little is known as to the fullness or purity of sound emitted by these bells. Bell-metal containing from 20 to 24 per cent of tin, with a leaning towards the higher amount, is claimed by some authorities as representing the ideal alloy for large bells, and, this being so, it follows that if the furnace charge is to include an admixture of scrap in the form of old bells, the resulting alloy can only closely approximate

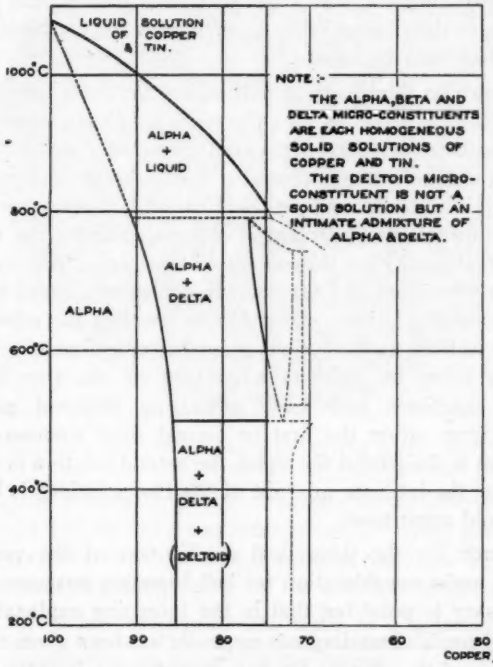

FIG. 9—THERMAL EQUILIBRIUM DIAGRAM OF COPPER-TIN ALLOYS

the ideal when "mixture by analysis" is resorted to in making out the furnace charge-sheet. The intentional introduction of other metals additional to copper and tin, although favored by some bell-founders, is of doubtful advantage, and where scrap also is included in the melt, the adoption of the "mixture by analysis" method of calculating the charge is rendered almost imperative if successful and concordant results are desired.

The rich sonorous qualities of the bronze used for large bells such, for instance, as church bells, is said to be due to the characteristic constitution or microstructure of the metal in general use for this class of bell. Fig. 9 represents a portion of the thermal equilibrium diagram of the copper-tin alloys. This diagram in its entirety is of a somewhat complex character, and, for the sake of simplicity, only that portion of the diagram covering the copper-tin alloys having a bearing on the constitution of bell-metal has been included.

Reference to this diagram will show that those alloys containing from little or no tin up to as much as 13 per cent of this metal, when cast and allowed to cool down very slowly to the ordinary atmospheric temperature, consist wholly of a solution of one metal in the other and are therefore of homogeneous structure; only one micro-constituent is observable under the microscope. The alloys with a tin content of between 13 per cent and 28 per cent when cast and very slowly cooled are found to consist of two solid solutions, one richer in tin than the other, and in addition to these two solutions a further constituent is in evidence, this being an intimate admixture of the two beforementioned solutions, and itself possessing different physical properties from either the first or second solid solution. The first solution is designated the alpha, the second solution is known as the delta; the intimate mixture of the two solutions is known as the deltoid constituent.

So much for the theoretical constitution of the range of alloys now under consideration for bell-founding purposes. It is only necessary to point out that in the foregoing explanation of the thermal equilibrium diagram emphasis has been given to very slow cooling of the alloys. Such a procedure as is indicated by the words *very slow cooling* does not appertain in foundry prac-

tice. Bell-metal cast under normal conditions and subjected to the usual "cooling out" may be regarded as constitutionally consisting of the alpha-solid-solution plus the deltoid constituent. To the presence of this latter constituent, distributed throughout the alpha-solid-solution, is ascribed the pleasing sonorous quality of bell-metal round about the 80:20 type of alloy.

The more uniform the distribution of the deltoid constituent, the more likely is the bell-metal to possess a full rich tone.

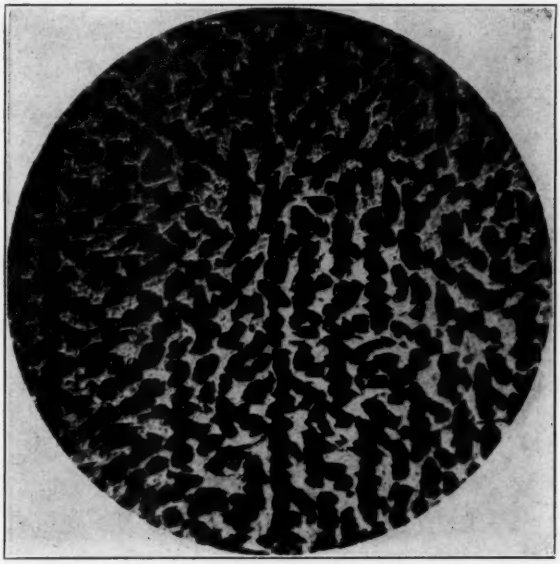

FIG. 10—PHOTOMICROGRAPH OF BELL METAL

Fig. 10 is from a photomicrograph of an alloy of the type mentioned, the deltoid constituent being the white portion. The etching reagents most suitable for the preparation of specimens of bell-metal for examination of the micro-structure are:

(1) A solution of ferric-chloride, useful as a means of identifying the deltoid constituent, which is rendered visible as a bluish-white constituent upon etching the metal with this reagent.

(2) A solution of sodium-picrate, which reagent serves to darken the deltoid constituent.

The mechanical properties—at atmospheric temperature—of ordinary sand-cast bell-metal may be briefly noted. The tensile strength is round about 15 tons per square inch. Those alloys with a tin content of 18 per cent and over have zero elongation, and generally speaking, are very hard and brittle; these properties

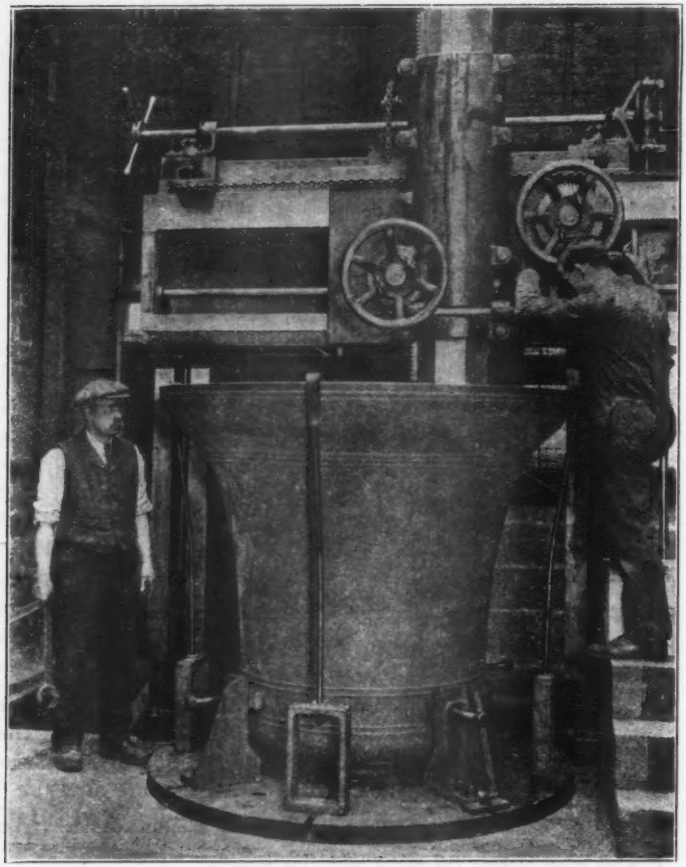

FIG. 11—BORING THE INTERIOR OF A LARGE BELL

are more accentuated as the tin content of the alloy increases. Annealing in the case of castings in these alloys renders the distribution of the hard constituent more uniform, with less liability of failure under the stresses set up by severe shock or repeated impact on the metal. By reason of the inherent brittleness of

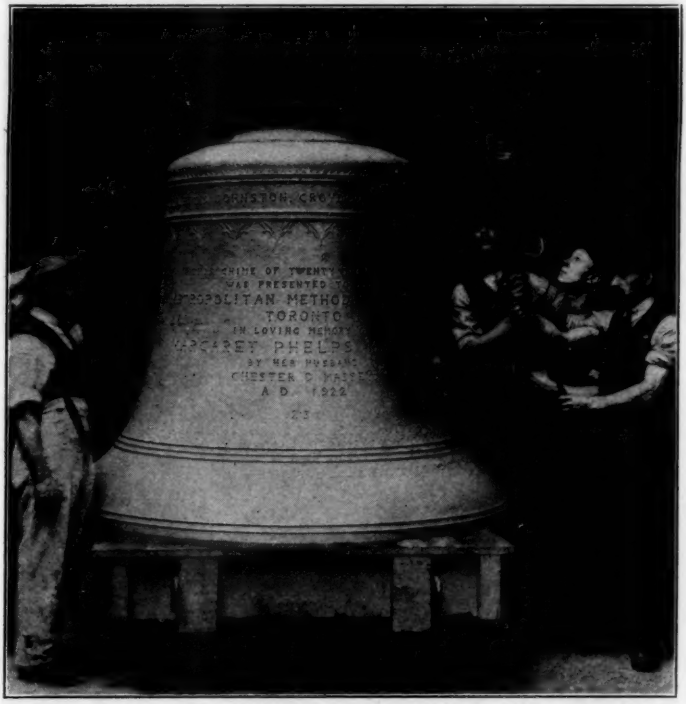

FIG. 12—FINISHED BELL. A GOOD EXAMPLE OF THE MODERN BELL FOUNDERS' ART

castings in the tin-rich cupreous alloys, the addition of other metals is attended with risk, and in some foundries no metals additional to copper and tin are intentionally introduced, the presence of any other metal which may be found in the casting being accounted for by the use of scrap.

FIG. 13—A LARGE BELL

Lead is often present to the extent of 1 to 4 per cent. The one-time popular idea that an addition of silver improved the tone of bells is without foundation, and is now abandoned; nor can the author justify on metallurgical grounds the sacrifice of the Chinese foundryman's daughter who plunged into a bath of molten bell-metal to ensure a soft tone for the temple bell about to be cast. It is a *sine qua non* that exceedingly brittle metal should not be used in a bell casting, neither must the alloy be too soft; the useful life of the bell is to a large extent dependent upon its capability of resisting the effect of repeated blows.

The color of good cast bell-metal has been described as "a peculiar gray-white." A newly fractured piece of cast bell-metal of the 80:20 type exhibits a white-gray, more or less crystalline surface, not infrequently spotted with small golden yellow patches; the presence of the latter is more noticeable in the absence of pressure feeding. The yellow patches indicate a lack of sufficient liquid metal to comply with the demand of "crystal growing" during the transition period which appertains as and when the metal as a whole passes from the partially liquid to the all-solid state. The bright yellow color of the patches is due to the light reflected from the undamaged natural surfaces of the members of the partially-formed crystals.

The dendritic structure of a newly fractured piece of bell-metal, as viewed under the microscope, is characteristic of the high tin bronzes when cast at suitable temperatures, and the structure serves in a useful way to grade these bronzes in relation to the percentage of tin in a particular alloy.

The compounding of a mixture of copper and tin to form a bell-metal alloy is not difficult. The bronze may be either ingotted and remelted, or made and used direct in a casting. The manufacture of ingot bell-metal follows the usual practice carried out in the making of ordinary high-grade bronze ingot, and calls for no special remarks. The furnace charge for the casting of large bells is generally prepared from either ingot copper or heavy scrap copper, an addition of a liberal weight of old bell-metal, if available, is often favored. The requisite quantity of tin is added before tapping; the weight of tin to be added depends largely upon (a) the quality of the alloy desired, (b) the weight of

copper included in the charge, (c) the weight and composition of the scrap. When large quantities of copper are melted "poling" is sometimes resorted to in order to bring the copper into its best condition. Charcoal is added to the furnace charge, and furnishes a suitable cover to protect the metal. For large casts an open-hearth air-furnace is generally employed, and proves quite suitable for this purpose. Pyrometric control of the melting and pouring temperature is desirable when the best results are demanded.

W. L.

Discussion—Modern Bell Founding

By C. Meneely, Troy, N. Y.

This treatise describes the manner in which scrap copper and old bell metal are used in preparing the composition for the bells, and, in considerable detail, tells how attunement is arrived at by boring instruments which scrape off some of the insides of the bells.

It so happens that our foundry has been located at Troy, N. Y., for many years and we claim to produce the highest priced and best bells made anywhere. Not for one moment would we consider using for our bell composition any scrap copper or old bell metal. Our bells are composed strictly of 78 parts best new Lake Superior copper and 22 parts best new block tin. Moreover, in the selection of bells forming peals and chimes where correct attunement and uniform tone color are so important, a sufficient number of bells are chosen to select from to make unnecessary the use of boring or scraping machines; and the bells are so correctly patterned that when they are cast they leave the molds perfect in musical tone. The numerous bells which are not found suitable in pitch or tone color for use in the peals and chimes in which they are tried out are sold for towers where single bells are required, thus preventing the very substantial loss that would result if the rejected bells had to be recast. It goes without saying that the cheapest way of constructing a set of bells is to cast the number desired and bore, chip or grind them to pitch, and it is well understood by the leading bell founders of this country that foreign bell founders who make their attuned sets of bells in this way, which is the method described in the treatise that prompted this letter, do so for economical rather than musical reasons, and sets of bells so made are never acceptable to those possessing critical ears.

Discussion—Modern Bell Founding

A. B. Root: While I would not be in position to take part in the discussion of this paper with the gentleman who has presented the written discussion, I happen to remember the very recent case of the installation of a carillon for bells similar to the one shown on the inside cover of this pamphlet. This carillon consisted of twenty-three, as it did in this set at Toronto, and was presented for a little church in the neighborhood just outside of Boston, at Cohassett. The bells were dedicated about three weeks ago as the bells of Cohassett. They had to go to England for those bells. It is interesting to know that in this kind of a set of bells the bells must not only have three tones in harmony with each free tone of the other twenty-three bells, but that in addition to the three tones there are four secondary tones and each of those secondary tones must be in harmony, so that it makes an exceedingly delicate instrument when properly made. In my opinion this paper deals with that finer art of the making of that kind of a bell rather than of the making of a single bell or bells of eight or ten for the ordinary belfry chimes which we hear so frequently throughout the country. I understand that such bells as these in Cohassett and in Toronto are quite rare in this country, and there probably are not more than three or four sets of bells in existence in this country. I think that the paper deals with that stage of the art rather than perhaps the stage discussed by the written discussion.

H. C. Estep: Possibly in defense of Mr. Lambert, who is unfortunately unable to be here and speak for himself, I might take upon myself, having known him for a good many years, to speak for him. In reference to the written discussion I would like to say that Mr. Lambert and Mr. Hall both are not rule-of-thumb foundrymen, but are highly skilled, educated foundrymen and do not proceed on rule-of-thumb methods. Although it mentions in the paper the use of scrap in these bells which the gentleman from New York particularly criticized, you must not assume that this scrap is melted in the furnace and then poured directly into the bells, as perhaps the gentleman who wrote the discussion in Albany has assumed. The scrap and metal is ingotted first, and the ingots are very carefully analyzed until they know just what they contain, and then they are remelted and cast into bells. If you will look on pages 195 and 196 of Mr. Lambert's paper, you will see that he makes it quite clear when he says, "The resulting alloy can only closely approximate the ideal when mixture by analysis is resorted to in making out the furnace charge sheet."

Making Copper Castings From Cupola Melted Metal

By T. F. Jennings, Garfield, Utah

The casting of copper in sand molds has always been attended with considerable difficulty because of the fact that copper, like most elementary metals, absorbs gases while it is being melted. These gases being retained after the metal becomes solid produce a structure resembling a sponge, and the defect for that reason is known as sponginess. This difficulty, being productive of unsatisfactory results, has created a certain prejudice against the use of the metal in the minds of some foundrymen, which is entirely unjustified. There is no reason why copper castings cannot be produced just as easily and readily as castings of iron, or any other metal, if certain fundamental facts, peculiar to the metal while in the molten state, are observed. For acid-resisting purposes it is the opinion of the writer, that approximately 50 per cent of the castings made in iron, should be made of copper. It is tougher than iron, and can be made quite hard.

Common Causes of Defects in Copper Castings

Sponginess, blowholes, porous or unsound castings are the usual causes of rejections in the case of copper castings. Occasionally, castings of this character can be used; but as a general rule they are unfit for practical use, and if their true character is not discovered before they are placed in service, they are liable to cause trouble, expensive delays, and perhaps serious accident.

Pores or blowholes in castings, sometimes are caused by wet or hard-rammed molds, or cores. The principal cause, however, lies in the metal itself, for it is a peculiar fact, that copper, like a number of other elementary metals, and some alloys also, melting above 1000 degrees Cent., when cast in sand molds will

produce gaseous castings. This condition will occur, no matter how carefully they may be melted, and handled, unless some metal or flux is added to the melt to "deoxidize it," as it is termed.

Need for Deoxidizers

The substance with which the copper is treated is generally known as a "deoxidizer," that is, an oxygen remover, which would lead to the supposition that oxygen was the gas responsible for the porous condition of the metal. There appears reason to believe, though, that sulphur has an important part in the production of the gas, as sulphur and oxygen react and form the gas, sulphur dioxide, which if generated within the molten metal might be retained and so produce this condition of porosity.

While it is not the intention of the author of this paper to enter into a discussion concerning identity of the gases responsible for the unsoundness of the castings as it is a subject he has not taken the time to study; it will be evident that it is advisable whenever copper is being melted for castings, that it be protected as much as possible from contamination by both sulphur and oxygen.

Furnace Factors

Accordingly many foundrymen prefer to melt their copper in crucibles, as it is comparatively quite easy to protect it with a covering of charcoal, or of some suitable flux, especially when natural-draft melting furnaces using solid fuel, are the melting medium. In the case of oil or gas-fired furnaces even with crucibles it is less easy to protect the metal from the gases, as the force of the flame blows away the charcoal covering, making it necessary to use something on the order of a flux that will melt and cover the surface of the metal, and which will not be displaced by the force of the blast. When melting with non-crucible furnaces consuming oil or gaseous fuels, it is more difficult to protect the copper than it is in the case of the crucible furnaces, as there is intimate contact between the flame and the metal. Electric furnaces should theoretically be excellent melt-

ing mediums for copper, as the furnace can be worked closed, or open as thought best. The cupola furnace, as used for cast iron, has the reputation of being the most unsatisfactory melting medium that can be used for copper, and most non-ferrous alloys, as the metal, fuel and air blast are in intimate contact during the entire melting period. Many foundrymen are of the opinion that this furnace cannot be used for melting such metals and alloys.

The Use of the Cupola in Melting Copper

As the author has had considerable experience in making light and also heavy copper castings from cupola-melted metal, it may be of interest to give an outline of the methods used, as some of the copper castings made from the cupola have weighed up to five thousand pounds, with walls from three to seven inches in thickness, and about forty per cent were finished all over on the outside.

Cupola Preparation

The cupola used was a No. 3, Whiting cupola, which was put up in the same manner as for an iron heat, except that care was taken to have the wood used to start the fire on the bottom, free of all iron, in the shape of nails. This is a precaution that should always be taken when non-ferrous metals are to be melted. It is, of course, unnecessary in the case of iron melting, but important for copper, and is mentioned at length because it is one of those little things, necessary for success, so easily overlooked. In order to protect the copper as much as possible from the sulphur in the coke, it was sandwiched between layers of charcoal; thus instead of charging copper directly on top of the coke bed, the charges were made as follows: The bed charge consisted of 600 pounds coke, charcoal 45 pounds, and copper 1,250 pounds. The charges following the bed consisted of charcoal 45 pounds, coke 60 pounds, charcoal 45 pounds, and copper 1,250 pounds. The entire amount of copper for each heat was thus protected by layers of charcoal from the sulphur contained in the coke. A mild blast was

employed, eight ounces, and the slag hole was not opened during any of the heats which ran about 15,000 pounds each.

Calcium Chloride Used As a Fluid Slag

We used a high per cent of copper wire in the charges and ran the heats 15,000 pounds, in from one hour to one hour and fifteen minutes. After the copper was melted it was tapped into a ladle of suitable size, which had been previously heated with an ordinary ladle torch heater, for about one-half hour. About ten minutes before the metal was tapped into the ladle about one-half of one per cent of calcium chloride was placed in the bottom, which when the copper is tapped onto it makes an absolutely air-tight covering.

Precautions When Using Calcium Chloride

This chemical, however, must be used with caution as it contains water, as water of crystallization, and in addition it absorbs water from the atmosphere when exposed thereto, which would cause an explosion if the chloride was submerged in the copper, as it would be if dropped into it. By adding it in the bottom of the heated ladle the water is driven off and there is no danger of metal flying. In addition to the calcium chloride, a generous layer of charcoal is placed in the ladle immediately before the furnace is tapped. A few handfuls of silica sand was thrown in the lips and stirred in well to stiffen the slag.

Phosphor Copper as a Deoxidizer

The deoxidizer used was one per cent of phosphor copper, containing fifteen per cent phophorus, and this is the way we used it: We handled the metal in 5,000 pound ladles and drew the metal in three taps; after the first tap we added the phosphor copper, the slag cover stuck close to the sides of the ladle and kept it from evaporating and the two following taps mixed it well without stirring or poling. To avoid the fumes and smoke and have prompt crane service, we brought the metal down after the whistle blew, and carried the metal from cupola to molds in about one minute and poured it at about 1,950 degrees Fahr.

Pouring Precautions

In pouring the castings the rate of pouring was diminished just before the mold was filled. Whenever heavy risers had to be put on, a small piece of phosphor copper was always dropped into each one and the riser was churned until it set; the hot metal to supply the shrinkage during the churning being obtained from a Hawley Swartz small furnace, run especially for the purpose.

Sand and Molds

An open facing was used composed of half red sand and half sharp sand and one to twenty (1 to 20) of core compound. We did not use seacoal or coke dust on account of gas and sulphur. In ramming the molds the rammer was always kept about one inch away from the pattern, and the molds were very thoroughly and carefully vented.

In making heavy castings of copper, the practice has always been to dry the molds, and to pour them from the bottom, using cores to carry the metal down and into the mold cavity.

Hardening Copper

When the copper castings are to be used for "acid-resisting" purposes, or where hard wearing qualities were demanded, it has been our custom to add from two to four per cent of an alloy composed of sixteen per cent chromium and one per cent phosphorus, the balance being copper. This alloy is made in a crucible steel melting furnace, the chromium being melted first, as a high temperature is required to melt the chromium. There are but two well-known methods of hardening copper; namely, by mechanically working it, and by the addition of some alloying element.

Pouring Heavy Copper Castings

When pouring the molds for heavy copper castings it is necessary to keep the pouring basin full of metal all the time the mold is taking metal; great care being necessary to guard against the metal sucking air into the mold with it, as under certain conditions it forms gas, which being absorbed by the molten copper, causes "spewing up" in the risers.

Both large and small copper castings are most frequently made in molds of sand, though iron molds are sometimes found desirable for casting terminals for electric furnaces using large amounts of current, more especially when heavy copper cables are cast therein.

Skillful Operation Necessary

To succeed in getting sound copper castings the melting has to be carefully and skillfully conducted, *no matter what kind of a furnace is used.* This applies to the cupola, probably more than with any other furnace, and the method the author has attempted to outline has given very good results. The castings made were not intended to be used for purposes where high electrical conductivity was important, otherwise, the phosphor copper could not have been used as a deoxidizer, and as a consequence it might have been more difficult to eliminate the gases and obtain sound castings. This we do not know, as it has not been necessary to make such castings.

Brass castings can also be made from cupola-melted metal, if the same precautions as described are used in melting the copper. The zinc, however, should be added in the ladle. To prevent chilling of the copper, the zinc must be pre-heated to a temperature just below the melting point. In the case of either brass or copper it is necessary to have it hot, when it is melted in a cupola furnace.

Discussion—Making Copper Castings From Cupola Melted Metal

CHAIRMAN G. H. CLAMER: The information contained in the paper of Mr. Jennings is indeed of a startling nature. I think if the question had been put to any of the non-ferrous metallurgists here as to whether he would have been successful in making copper castings by that method, it would have been predicted that he was doomed to failure. Evidently, however, Mr. Jennings, under the stress of circumstances, was forced to use a cupola and did meet with success. As he has stated, the castings were not used for electrical purposes, and that copper melted under such circumstances would not meet the requirements for high conductivity. No doubt there are some gentlemen here who would like to present a

discussion or ask some questions. I am sure Mr. Jennings would be pleased to answer them.

MR. DECKER: Were these 12-foot castings machined, and did you find any blow holes in them?

T. F. JENNINGS: I will say, as I mentioned there, about 40 per cent were machined and with one exception they all machined fine. To give you an idea of what these were, they were trunnion bearings that run on a sixteen-inch shaft, and they were turned up inside and outside. They were flanged on both heads.

P. W. TURNER: I would like to ask Mr. Jennings if he has any special preparations for the melting zone or any particular place in his cupola where he melts, and whether he raises his bed in melting copper and whether there are any peculiar preparations for melting iron?

T. F. JENNINGS: I would say that before we started on this work we went all over it and planned it out and we made no additional preparations any more that just what I have explained to you. We were somewhat timid when we started, from the fact that we had an experience of making brass at one time, and the first time it was not successful and it taught us a valuable lesson, but this was new to us in a way and we were timid, but we went over it carefully and did it just exactly without any special reducing of our blast.

CHAIRMAN CLAMER: As I understand it, you did not change the height of bed as compared with melting iron?

T. F. JENNINGS: Not at all; it was about 18 inches above the tuyeres.

A. BREGMAN: I would like to ask Mr. Jennings, in view of the fact that they state this installation was not commercially possible under normal conditions, how small an installation do you think could be managed and made to pay, of that sort? How small a tonnage could you run and still make it pay?

T. F. JENNINGS: There is an old saying that necessity is the mother of invention. Now my object in presenting this paper here today is to place this matter before foundry men who may be situated just the same as we were. We have a nice brass foundry with a crucible furnace and another furnace that we do experimental work with, but we could not make the large castings which were necessary. When our casting size got beyond our regular brass melting equipment then we had to use the cupola.

GEORGE CLINK: What percentage of loss did you have, Mr. Jennings, have you got any data on that?

T. F. JENNINGS: We have no data on it, the loss was very little, it was so small that it was not noticeable at all.

P. W. TURNER: My loss is about one and a quarter per cent; I judge 1.25 loss.

E. R. DARBY: I would like to know the effect of pouring temperature up or down on that given by Mr. Jennings.

T. F. JENNINGS: I expected in coming here today that that question was going to be fired at me from different angles, as to the temperature. Now, gentlemen, I have taken this matter up with the highest authorities that I know of and their opinions differ. Some will say 2100 and 2000 degrees Fahr. We heated the metal to about 2200 degrees Fahr. We poured at about 1950 or 2000 degrees Fahr.

G. K. ELLIOTT: I might say just as a matter of indicating that nothing has been done very lately, that about fifteen years ago I was in a steel foundry in Western Pennsylvania, and they were running about 5000 pounds of copper per day in a homemade cupola; to make gun metal. They melted the copper down and added tin in the ladle, and the castings they made and which were all machined up seemed to be very good castings. That is the only instance I know of cupola melting up to this one presented by Mr. Jennings. There is a paragraph entitled "Hardening Copper," which is rather interesting to me, and in which I think the non-ferrous metallurgists in the U. S. are interested to a certain extent, because about monthly we have foisted on the long-suffering public by the non-technical press, stories of inventors discovering the long lost art of hardening copper by some blacksmith. Not long ago some artisan in St. Louis is reported to have discovered this long lost art and sold the secret to some Detroit concern for a million dollars. This news was copied all over the United States and one of our national magazines had an editorial on the subject. I think it is time for us to get out and tell these would-be inventors that there is no such thing as the long lost art of hardening copper, that any metallurgist can name half a dozen different ways of hardening it, and thus put an end to these stories about the discovery of the long lost art of hardening copper. If we can get that to the public, we will save a lot of would-be inventors a lot of trouble.

GEORGE CLINK: Mr. Elliott made a remark about melting copper 15 years ago. In 1898 we did the same thing for the Concourse Power Company. They had castings that weighed about 500 pounds apiece, and we used practically the same method Mr. Jennings used in charging the cupola, had layers of charcoal intermingled with the coke. In tapping the ladle we tapped part of the mix at the different charges and all the castings came out very successfully. About eight or nine years ago we made some castings weighing 30,000 pounds and charged that in the same manner, using 4000 pounds of copper to the charge. We had the ordinary cupola bed and eight inches of charcoal intermingled between each charge. We made the test of the first metal or we took tests of the metal after we had it all in the ladle, a 40,000-pound ladle. We had a special stirrer with paddles similar to an ice cream freezer. It was hung on a crane. In that manner we thoroughly mixed the metal. A chemical test was made from the first metal taken from the ladle, and the cast metal, after the casting was poured, was very little different from the chemical test of the material. I just mention this because Mr. Elliott

said it was the first time he heard of melting that amount of metal. That was 15 years ago and this was a considerable time ahead of that.

CHAIRMAN CLAMER: Some of the large pump manufacturers making acid resisting pumps have been using the cupola for many years in melting that kind of alloy, which is, as a rule, copper, tin and lead, but the startling part about Mr. Jennings' paper is that he melted copper which was fairly pure.

The Founding of Brass in Mexico

By H. H. Miller, Torreon, Coah., Mexico

There are no available government reports or data of any kind covering the foundry industry in Mexico. There are no foundry associations, no foundry publications, and no attempts at cooperation or exchange of ideas between foundry owners and operators. Each foundryman and would-be foundryman works out his problems the best he can for himself and then as a rule is not inclined to give useful information to his neighbors and competitors.

In view of these facts, a paper on the founding of brass in Mexico will be more or less a story of the personal experiences and observations of the writer. The statements I make and the conditions I describe will apply in general to the whole republic.

The Consolidated Rolling Mills & Foundries Co., of Mexico City, have perhaps the best equipped non-ferrous foundry in Mexico. They operate it in connection with their steel plant and make brass and bronze castings of all kinds, and a standard line of globe valves that compares favorably with the U. S. product. There is another brass foundry in Guadalajara, state of Jalisco, making a line of valves. Aside from these plants I do not know of anyone manufacturing a standard line of either brass or aluminum goods or the market. There is no cold-rolled, sheet or ornamental brass made in Mexico.

With but a very few exceptions all of the brass foundries, aside from some that are operated by mines, smelters and industrial plants to take care of their own work, are run as adjuncts to iron or steel foundries and in some cases to blacksmith shops. They do strictly a jobbing business and most of that for customers in their immediate vicinity.

Their orders come from mines, smelters, railroads, ranches and industrial plants for reserve stocks, repairs and replacements. This takes in a wider range of work than usually goes to the jobbing shops in the States because of the difficulties and delays incident to getting machinery parts and repairs from the U. S. and Europe. Here, instead of wiring to the factory or a service

station for a new part when something breaks, the general custom is to go to the local foundry or machine shop and order one made. The cost is usually considerably more than that of a piece from the factory and it may not be as well finished, but if it will answer the purpose and can be delivered promptly the question of price and appearance is not considered. Very often pieces of cast and malleable iron are replaced with brass castings and a few brass foundrymen who have a reputation for giving prompt attention to rush jobs take quite a number of these orders away from the iron foundries that as a rule are slower on deliveries.

In the days before the revolutions the plants carried large reserve stocks of everything they were likely to need for several months, and even years ahead; but during the last few years they have been drawing heavily on these reserves and buying only whatever was needed for immediate use after stocks were exhausted.

In some parts of the country the work for the sugar mills and refineries is a large item, but I am not familiar with it and can not say anything about the class of their castings. Here in Torreon, while the volume of work we do is not so very large, it is quite varied.

For the local smelter we make the class of castings mentioned above but in smaller quantities. For the cotton seed oil mills and soap factories we make several kinds of pipe fittings, press boxes, soap dies, gears, pinions and many special castings as well as the regular line of round and hexagon sticks, bushings and general repairs for pumps, motors, engines, etc.

The Laguna district of which Torreon is the commercial center, is primarily an agricultural country and the success or failure of the crops depends to a large extent on the flood waters of the Nazas river. When there is plenty of water and not too much revolution the ranches give a lot of work to the foundries and machine shops. They use some brass in the cotton ginning plants, the narrow gauge locomotives and cars, steam engines, gas and gasoline engines and pumping plants. There are still some old style gin presses in operation using a brass nut weighing about five hundred pounds and once in a great while we have an order for one of them. The hardest jobs we get from

the ranches are runners for the centrifugal pumps used for irrigation. They require expert pattern makers and core makers.

We have cast about ten church bells in the past two years.

Very few aluminum castings are made in Mexico. We probably use more aluminum for patterns than anything else, and most of them are made from scrap aluminum.

A large per cent of the brass castings used in Mexico are cast entirely from scrap brass. Many of the master mechanics at mines, smelters and industrial plants "make their own" brass castings. Their equipment generally consists of a small coke furnace, a pair of tongs, a crucible and whatever kind of molding sand they can dig up in their immediate vicinity. They use scrap brass with no fluxes or deoxidizers. While no one of this class makes very many castings and no large ones at all, still there are so many of them that in the aggregate they take a considerable amount of work away from the regular foundries.

I do not want to leave the impression that I include all the foundries operated by the industrial plants, mines and smelters in the class just mentioned, but the exceptions are few and far between. The American Smelting and Refining Co. and the Penoles Mining Co. have foundries for both brass and iron in connection with their Monterey plants, and the A. S. & R. Co. with another at Aguascalientes. All three of these have good foundry equipment, are handled by competent foundrymen, and turn out good castings.

At times during the revolutions some of the regular foundries were closed down, leaving a number of molders out of employment. Some of the molders joined the revolutionists and became captains or generals and others opened up brass foundries from time to time. Their foundries were generally in the corner of a blacksmith shop or small machine shop, and their equipment was extremely limited. The native Mexican has the world beaten for inventing laborious and complicated ways for doing a simple job, and on the other hand sometimes of doing a difficult job with whatever crude means he may find at his disposal. If our friend Pat Dwyer could have taken a trip through this country while the local revolutions and the world war were both on and visited these makeshift foundries, his comments on them would have been interesting.

If fire bricks were not available for furnace lining, common construction bricks were used and sometimes even the sun dried adobes. When the world war cut off the supply of crucibles, they built cupolas of old boiler shells, sections of smoke stacks, or galvanized iron tanks, and used hand driven forge blowers for their air supply. For small castings up to four or five pounds they set a clay lined ring or shell on the blacksmith forge and used the cast steel body of the 3 inch shrapnel shells for crucibles. These were inexpensive crucibles and the supply unlimited, for the landscape here was pretty well sprinkled with them from time to time.

As a rule they did not know anything about fluxes or the compositions of high grade bronzes so the lack of prime materials did not bother them. One of our molders once told me that the only "liga" (alloy) they used was a little copper sometimes.

Since the railroads have been under government management, they have installed iron and brass foundries in most of their shops. They have ten or twelve in operation, but I am not in a position to say anything about the class of work they turn out nor of the efficiency of their organizations.

As I have intimated before, all kinds of devices for melting are employed. I know of only one electric furnace being used for brass and that is a 750 pound capacity furnace in the Consolidated Rolling Mills & Foundries Co., of Mexico City.

For linings I think most of the foundrymen use whatever they can find closest at hand. The railroad shops use regular fire brick that they chip to more or less of a wedge shape and set in fire clay and high silica sand. Here we use fire clay purchased from the local hardware stores and a sand, found in certain parts of the bed of the Nazas River, that runs about 92 per cent silica. We mix one part of the fire clay with two parts sand and ram it in the two halves of the furnace shell around a wooden core. By patching it once in a while we get from 30 to 50 heats out of a single lining. The only cost of the sand is that of hauling it a distance of about two miles from the river, so linings are not very expensive.

Perhaps eighty or eighty-five per cent of the brass furnaces in use in Mexico are of the pit type for coke and crucibles.

Some use cupolas for the larger castings and for very small ones improvised furnaces on the blacksmith forges.

There are no deposits of molding sand that I know of which are being exploited and offered to the foundry trade. Molding sand takes a high freight rate here, being put in about the same class as fire clay and if shipped any long distance the cost is almost prohibitive, so each foundryman tries to locate a sand supply as near as possible to his foundry and get along the best he can with it. My sand supply is less than two miles from the foundry. I can not say very much for its quality, but so far it is the best we have been able to find.

In the railroad foundries all the molders and, so far as I know, all the superintendents and foremen are Mexicans. In most of the larger privately owned foundries the foremen are foreigners and all the molders natives of the country. Under proper direction and with proper training, they make good molders and some do just as good or better work than the average American. As a general rule, however, they work slower and require more helpers than in the U. S. A. They lack initiative and it is difficult at times to get them to adopt new methods and then to keep them from drifting back to the old ones to which they have been accustomed. The Mexican is a slave to custom and likes to do things as he has always done them and as his forefathers did before him. He shirks responsibility and is never at a loss for a reason outside of himself for anything that turns out badly. It happens frequently that he will use an infinite amount of care and patience in doing a difficult piece of work and then slight some easy and insignificant part (like anchoring or venting a core or putting on enough weights or clamps), and lose the casting.

A pattern maker in a jobbing foundry in Mexico has to be an expert to be able to handle all the jobs that come in to him. There are a few here as proficient in their line as can be found in any part of the world and who are equal to any and all emergencies. There are many more, though, of the class ranging from mediocre down. Most of the first mentioned class are foreigners and the better class of Mexican pattern makers have been their understudies.

One of my customers thinks he has a pattern maker. What

he sends out, however, are really models of what he wants, holes and everything, with no signs of core prints nor core boxes. Not long ago he sent me a wooden bushing six inches in diameter, eighteen long, with a four inch hole through it. To facilitate molding he made it in two halves put together with dowel pins. This fellow is an advocate of split patterns, but very often splits them in the wrong place.

I think we use old and broken iron castings for patterns here more than they do in the States. I have heard American molders use profane language when this kind of a job is handed to them. A Mexican molder would have taken it as a matter of course and patiently worried along with it until it was finished. Sometimes we make gear wheel molds from old broken ones and, where teeth are missing, cut out in the sand so that part of the rim will be solid. The customers ask for them that way and cut in the missing teeth with a hack saw and a file. They would rather do this than pay for a pattern.

The wag that made the remark about the first hundred years of married life being the hardest might have said the same thing about trying to build up a foundry business in Mexico. It takes time, patience, and most of all personal contact and acquaintance with your customers to build up a regular trade. Neither circular nor personal letters nor any kind of advertising go very far towards getting your first orders. When I decided to start in the brass foundry business I sent out circular letters to everybody I could think of as prospective customers. Now in this country many people will answer communications that the average business man in the U. S. would throw in the waste basket without even reading, so in answer to my first circulars I received a number of courteous letters from individuals and companies telling me how much pleasure it gave them to know I was going to open up a brass foundry and assuring me of their orders just as soon as they should need something in my line.

I thought I was going to start off with a big rush, but I guess they also had waste paper baskets and that my circulars landed there immediately after they had been answered, for I did not receive their orders. Other circulars and personal letters were sent out with about the same lack of results, and then

I tried going after them personally. It has nearly always taken a personal visit, and in some cases several scattered over a number of years, to get the first order; but after the first the rest come easier. When you once get the trade and confidence of an individual, company, or corporation here, they stay with you pretty well and any new competitor entering the field will find it difficult to get them away. Still, a personal call once in a while helps to hold them in line, and it is a good idea to drop in between revolutions just to show them you are still on the job. So I find it worth while to get around to all of them as often as I can and I try to keep on friendly terms with everyone from the general manager to the portero. The portero is the fellow stationed at the extreme outer gate, and he sizes you up as you go in and come out. If you drive up in your car, he throws open the gate and gives you "paso libre"; but if you go afoot and he does not know you, he may ask you where you are going and what is your business.

To sum it up, then, the field covered by the brass foundries in Mexico at present is limited and not large enough to justify one in dividing it up and trying to be a specialist in any particular line. The few of us who have tried to separate ourselves from the iron and steel foundries and give our attention to brass, bronze, copper and aluminum casting, have to take all kinds of jobs that are offered to keep busy and hold our organizations together.

We know that Mexico is one of the richest undeveloped countries in the world and we know what can be done if it ever settles down and really goes to work. We still believe that this will actually happen some time, and when it does, we figure on being here and in on the ground floor. In the meantime, we are doing what we can to make the best of the immediate present.

Art Bronze Work

By J. F. Arnold, Mount Vernon, N. Y.

Early Biblical accounts inform us that Tubal Cain was an instructor of every artificer* in brass and iron, so at that early period, no doubt, bronze, silver and gold as well, played some important part in art; certainly in art, as we read that Abraham's servant bedecked Rebekah with golden ear rings and bracelets at the well in Mesopotamia. They were also skilled in the manufacture of commercial articles for we find that when Solomon wanted brass bath tubs, shovels and basins for the Temple, he sent for Hiram of Tyre, who cast them in the clay ground between Succoth and Zarthan.

Then on down through the ages, we have more or less of this class of work. When we entered the Christian era, there was no doubt that the crafts in this line were still carried on, as we are informed that the silversmiths revolted against St. Paul, as his doctrine would do away with their craft, which no doubt included bronze and brass as well as silver.

When we come to our own experience in the production of art bronze work, we find it difficult to write a description of the process unless some certain piece of bronze work is chosen as a subject, and even then our description is not complete in all its details.

We have chosen for our subject, the bronze statue illustrated in Fig. 1. Keep in mind that this statue is a finished piece of work on all sides, the top and the bottom being the only parts not exposed to view. You will note this statue is in a sitting posture. The dimensions are as follows: Base, 3 feet wide, 4 feet 5 inches deep, with a total height of 5 feet 6 inches over all.

Model Divided to Facilitate Molding

The model is furnished to the founder by the sculptor in plaster of Paris. Before starting actual work, there is generally a conference between the sculptor and the founder to

*Genesis iv, 22.

Figure 1.

determine the number of pieces in which the work is to be produced. In this case, we removed the head, foot and the hand with the biretta. It can be seen that the collar provides a good place to make a concealed Roman joint, as also does the drapery around the hand and foot.

The castings comprising the statue consist of four pieces, the total weight of which was 1,777 pounds made up as follows: Head, 38 pounds, hand and biretta, 29 pounds, foot, 12 pounds, body and chair, 1,698 pounds.

Piece Molding Process Followed

On receipt of the model at the foundry, it was carefully cleaned and given a coat of shellac varnish. When it was dry,

it was ready for the sand. In this case, the model was bedded in the flask, the back of the chair being down. A parting was then made along the molded lines of the back post of the chair and up around the shoulders. On this parting, began the first step of the piece molding process. The base projected 4 feet 5 inches above the bedding. Against this base there was rammed up a block of sand the width and height of the base, following the lines of the same and about 10 inches thick at the base and 6 inches thick at the top. It was reinforced with iron rods much the same as reinforced concrete. The rods forming the reinforcement were securely wired together and so placed that holes of sufficient size could be cut in the block so as to connect the core to it as this block eventually became the core print.

The same process was carried out at the neck of the model, the block, of course, being much smaller. These blocks being completed, we made piece molds of all the moldings on the side of the rear chair post and continued this process up through the fringe and drapery to the top molding of the front chair post, terminating even with the base on one end and at about the edge of the collar on the other end. On account of the fringe and drapery, there were a great number of small piece molds, the backs of which were kept flat but tapered toward the top. Each one of these piece molds had an indentation provided in it. When completed, these piece molds were covered with a reinforced sand block about 4 inches thick.

We treated the other side of the model in the same manner. Before proceeding further, we made reinforced sand strip molds across the exposed face of the model at convenient places. These strip molds were set aside for future use in getting the correct contour of the cope of the core.

We then piece molded the face of the model and covered it with a reinforced sand block, which was thick enough to come about even with the cheek of the mold. The cheek of the flask was then ready to be applied and rammed with sand or filled with plaster of Paris, plaster of Paris in this case.

Then the cope parting was made, the cope applied and rammed with sand. The flask was bolted together and buck

bars applied and bolted. The whole flask was then rolled over, the drag bedding removed and parting made. The back of the model was piece molded where required and the drag of the flask was applied and rammed with sand. The flask was then securely bolted together and rolled over, drag side down.

Making the Core

We then unbolted the flask and removed cope, cheek and reinforced sand blocks. The piece molds were removed one by one and secured to the reinforced sand blocks with paste and wire nails. The model was then free to be removed from the drag mold and any piece molds removed from it and applied in their proper place on the drag mold. We set in place the reinforced sand blocks which were to serve as core prints, first putting in them the necessary perforations to take the reinforcing rods. The drag side of the mold was covered with sheet paraffin the thickness of the metal required. We then applied the other parts of the mold and rammed the space left by the removal of the model with sand, reinforcing same with iron rods. This formed the core. The reinforced sand strips heretofore mentioned were then applied to get the correct contour of the cope of the core.

This core was the same size and shape as the model, except the drag side, which as you will recall was rammed on the sheet paraffin. All sides of the mold were removed, and we had the model reproduced in sand. We then went over this core and shaved the thickness of the metal from it. After the mold was dressed, it was baked in the oven until dry, then removed, assembled and poured.

During all this manipulation, the matter of gates has been taken care of, as has also the size and position of the reinforcing rods that they may be removed from the casting. The same process only on a smaller scale applied to the molding of the head, foot and hand with the biretta.

Bottom Spout Basin Used in Pouring

In pouring these castings to insure as clean castings as it is possible to produce, they were all poured from a bottom

spout basin. The basin was filled with molten metal, plug withdrawn and a crane ladle at hand kept the basin full of metal, so practically no dross entered the mold.

Cleaning Operations Important

The casting was next removed to the cleaning department, the core, reinforcing rods, gates, sprues and fins removed; thence to the pickling and dipping department, where all sand was removed; thence to the finishing department, where the Roman joints were fitted, doweled and caulked and seams dressed. The chaser then went over it to remove any or all imperfections. When finished, it was oxidized to the tone required.

The Production of Aluminum-Alloy Pistons in Permanent Molds*

By Robert J. Anderson, Boston, Mass., and M. Edward Boyd, Clinton, Mich.

Introduction

Recently, the U. S. Bureau of Mines was asked by The Kant-Skore Piston Co., Cincinnati, Ohio, to make an investigation of the production of aluminum-alloy pistons in permanent molds, with the object in view of ascertaining the causes for wasters in manufacture and of defects in the castings. Certain of the results of this study are reported in the present paper, and the casting of aluminum-alloy pistons in permanent molds is discussed in general. In later papers, it is intended to discuss the results of the investigation in more detail, particularly in connection with the question of wasters and defects in production.

The casting af aluminum-alloy pistons for internal-combustion engines, principally automobile and aviation engines, is a comparatively recent development, dating only from the introduction of the light alloy piston in Europe in 1912-1913. At this time, European automotive engineers employed aluminum alloys in racing-car motors as a means of reducing piston weight and securing greater speed. During the late war, the aluminum-alloy piston was investigated at length for use in aviation engines, and its performance was so satisfactory that it was adopted as standard equipment on practically all types of aviation engines. The value of the light alloy piston in this field greatly augmented interest in its employment for motor-car engines, more particularly because of the development of the long-stroke, high-speed motor. As is well known, the aluminum-alloy piston is now standard equipment on many makes of motor

*Published by permission of the Director, U. S. Bureau of Mines, Department of the Interior.

cars, and it is also used in marine motors and other types of internal-combustion engines. The controversy as to the relative merits of aluminum-alloy and cast-iron pistons, from the automotive point of view, need not be taken up here, but there is no doubt as to the superiority of the former. The question of the aluminum-alloy vs. the cast-iron piston has been dealt with at length in automotive-engineering literature, and papers by Diamond,[7, 28] Gunn,[9] Jehle,[10] Pannell,[19] and others may be consulted* in this connection.

In practice, various methods are, or have been, employed for the production of aluminum-alloy pistons, including sand casting, permanent-mold casting, and die casting; in Germany, pistons have been made from aluminum-alloy sheet by pressing[16]. While the relative merits of these different methods cannot be discussed in detail here, it may be stated that the permanent-mold process is best adapted to the production of pistons, and has been used largely. Die casting is not a suitable process, since the resultant castings are porous and contain numerous blowholes which are revealed on machining; moreover, die-cast aluminum alloys are not reliable as to mechanical properties. Sand-cast pistons are satisfactory, but the production rate in sand founding is too slow as compared with permanent-mold casting, and the physical properties of sand-cast alloys are distinctly inferior to those of chill-cast ones. Moreover, permanent-mold-cast pistons can be made more accurately as to size and weight tolerances than can sand-cast pistons, and this means a saving in the cost of machining and a reduction in the amount of machining scrap and consequently of metal. For a given output, casting in permanent molds can be carried out with less floor space than is required in sand casting, and unskilled labor can be employed for operating the molds.

While considerable experimental work has been carried out on the production of permanent-mold-cast aluminum-alloy pistons, particularly in connection with gating problems and the design of molds, very little has been reported in the literature of the subject. In connection with experimental work carried out by the writers in gating pistons and studying the causes of and methods for the prevention of blowholes, investigation was

*Numbers refer to references in the appended bibliography.

made of the permanent-mold process in general, and the history of the process and its application to metals and alloys in general are discussed in another paper.[30] In the present paper, it is the writers' object to discuss the permanent-mold process in detail as applied to piston production and to give the results of some tests and observations made. It is hoped that the information given will be found of value by the light alloy industry.

Acknowledgments:—The writers wish to acknowledge with thanks the aid given by R. J. Owen, works manager of the Kant-Skore Piston Co., in carrying out the experimental work at the plant of the company, and also the permission given by H. J. Hater, treasurer of the company, for permission to state that the investigation was made at the plant of the concern in question. Thanks are also due to Dr. Léon Guillet for certain photographs showing French piston molds. Chemical analyses of materials used in the experimental work were made by Geo. B. Dalrymple, formerly analyst of the U. S. Bureau of Mines.

Principles of the Permanent-Mold Process, as Applied to the Production of Motor Pistons

As defined elsewhere,[30] the term permanent-mold casting is used to connote the product obtained by pouring liquid alloys into metallic molds, the alloy going into the mold under the force of gravity solely, and the final product being a finished or semi-finished casting. The process of making castings in permanent molds, whether aluminum-alloy motor pistons or other castings, consists essentially in pouring a liquid alloy into a previously heated and assembled mold, dissembling the mold as soon as the alloy has frozen, and removing the casting. The operations consist in assembling the mold, heating it to the proper temperature (in practice the mold is kept hot by burners), inserting the cores, and pouring the alloy. The cores are removed in the proper order and at a suitable interval of time after the alloy has been poured, and the mold is then taken apart so that the casting can be removed. The mold is then re-assembled, and the operation continued over and over again. The method of pouring is the same as in sand practice. The resultant cast-

ing has a smooth finished surface, and for some castings no machining may be required other than the removal of gates and fins. Considerable precision machining and grinding is necessary in the production of pistons. The principles of permanent mold casting in general have been discussed in detail by Johnson,[6] an anonymous writer,[20, 21] and by the present writers,[30] and here the process will be treated largely as applied to piston casting.

As in the case of die casting, the following three items are essential for the successful production of permanent-mold castings: viz., (1) a metallic mold which will withstand the action of the liquid alloy as well as rapid changes in temperature; (2) an alloy suitable for casting; and (3) a design of mold and casting and a method of gating which will insure the production of good sound castings. The essential steps in the production of finished permanent-mold castings are: (1) design of the casting and mold; (2) preparation and set-up of the mold; (3) melting and pouring the alloy; and (4) machining and inspection of the castings.

The fundamental principles upon which molds are built and operated are substantially the same, but there are various types of molds employed in different plants for the same type of casting. As pointed out in another place,[30] the general principles of permanent-mold casting have been patented by Székely,* and the operating features of the Székely mold have been discussed in detail.[1] The process of permanent-mold casting as applied to piston production may be conveniently described by reference to a typical patented mold, of which there are many (cf. Patented Molds, in later paragraphs).

Figs. 1 and 2 show the side elevation and top plan of a mold, patented by Bamberg,** for casting skirted pistons in light aluminum alloys. The mold is made up of a base member, 1, and complementary mold members or halves, 2 and 3; the latter are movable on the base member, 1, toward and from each other. The main core of the mold is indicated by 4; this is made up of a number of sections suitably recessed so as to

*U. S. Pat. No. 841,279, Jan. 15, 1907.

**U. S. Pat. Nos. 1,296,591 and 1,296.592, March 4, 1919.

form the bosses and ribs on the interior of the piston castings. Diametrically opposite core pins, 5 and 5, are arranged to project into the mold cavity to form openings through the bosses 8, 8, of the piston casting. These core pins are in the form of rods that are mounted in openings of the mold halves 2 and 3.

The mold halves 2 and 3 are formed with complementary cavities or recesses 6 and 7, which together form the mold gate. The gate thus formed, as will be seen in Fig. 2, is disposed mid-

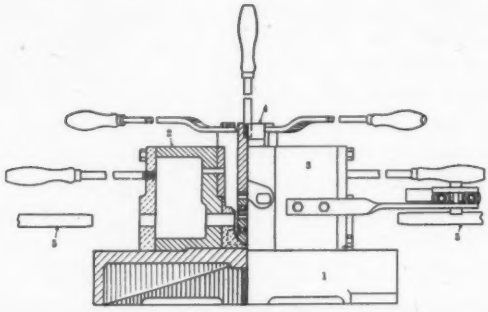

FIG. 1—SIDE ELEVATION OF PERMANENT MOLD FOR PISTON CASTINGS (BAMBERG)

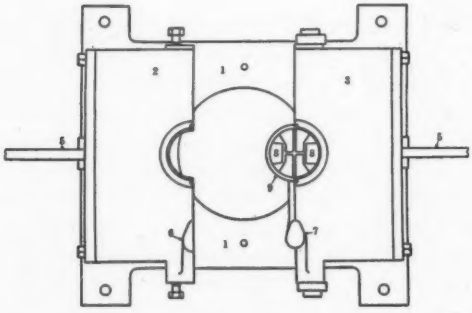

FIG. 2—TOP PLAN OF PERMANENT MOLD FOR PISTON CASTINGS (BAMBERG)

way between the internal bosses 8, 8, of the piston casting. The gate is constructed so that a liquid seal of alloy is formed on pouring, thus preventing the passage of air and gases into the mold cavity and also reducing splashing of the alloy within the gate on running a casting. Also, the gate is preferably formed so as to lead into the mold cavity at the top and bottom and at intermediate points between the top and bottom. Suitable means are provided for heating the walls of the mold halves 2 and 3. The core pins are kept preferably at a lower temperature than the other parts of the members 2 and 3. When liquid alloy is poured into the mold (at a temperature several hundred degrees higher than that of the mold walls), it is subjected to a very strong chilling action at the points adjacent to the core pins, 5, 5, and to a less marked, but still substantial, chilling action at points adjacent to other parts of the mold-cavity walls. The higher temperature of the gate walls insures the maintenance of liquid alloy in the gate until after freezing occurs in the mold cavity; hence, contraction is taken care of, in part, by the feeding action of the liquid gates.

In making a casting, the liquid alloy, at about 750 degrees Cent., is poured by gravity through the gate and into the mold cavity. The first part of the alloy entering the mold fills the bottom of the mold cavity (corresponding to the head of the piston), and thereafter the alloy flows from the gate opening in opposite directions, around the vertical cylindrical parts of the cavity—the level of the liquid alloy rising until the cavity is full. Hence, it will be seen that the alloy freezes progressively from the bottom upward and from the side of the mold cavity opposite the gate in a direction toward the gate. As the alloy rises in the mold, it fills the cavity forming the skirt, 9, of the piston. In a short time after pouring, the core pins, 5, 5, are withdrawn, and then after another short interval of time the core, 4 (made ordinarily of a multiplicity of sections), is taken out, the mold halves 2 and 3 are separated, and the casting is removed.

Substantially the same methods are described in other patents for the production of particular aluminum-alloy castings and more especially of skirted pistons (cf. patent numbers cited in later paragraphs). Methods of gating and coring are very

variable in connection with the design of molds for different types of pistons, and some typical molds are discussed in the following section of the paper.

Some Typical Examples of Piston Molds

Before dealing in detail with mold design, methods of gating, and mold operation, it is advisable to discuss some typical piston molds that are employed commercially. While, essentially, there are three distinct types of piston molds, these differ only in mechanical principles of make-up, although methods of gating are very variable. Many complicated designs have been used in production for pistons, but these are entirely unnecessary. With most molds, two men are required for operation (cf. Operation of Piston Molds below), but lately semi-automatic or so-called one-man molds, have been built which reduce operating costs. The most practical and economical type of piston mold consists of two halves, each containing part of the mold cavity and gates, mounted slidably upon a smooth base plate, and so hinged together that they part readily. A clamp or lock is provided to hold the mold halves firmly together while pouring a casting, and suitable handles are attached to the mold body to facilitate operation and movement of the mold. Metallic cores are normally used in American practice; these are inserted into the mold cavity and provided with handles so that they can be removed readily.

Types of Molds:—As mentioned, there are essentially three different types of molds employed for piston production, but these differ only in mechanical make-up, the principles of construction being the same.

The first type of mold, and probably the most simple from the point of view of design, consists of two mold halves mounted upon a flat base plate; this base plate forms the bottom inner wall of the mold cavity. The mold halves are opened and closed by means of handles which are attached to the halves, and the halves are held in alignment by dowel pins. Two halves forming the runner blocks and containing the pouring gate and riser are mounted upon the top of the mold-body halves proper; these runner blocks simply rest on top of the mold and are held in

position by dowel pins. These top halves are lifted off or onto the body by means of attached handles. Fig. 3 shows this type of mold in the assembled position ready for pouring, while Fig. 4 shows the same mold dissembled. The mold shown is employed in French practice,[17] and a sand core is used therewith. This type of mold is easily and cheaply made but it is not well adapted for rapid production and is altogether too slow in operation for American practice. The French metallurgical literature indicates that this type of mold is employed largely in France for most kinds of permanent-mold castings in aluminum alloys.

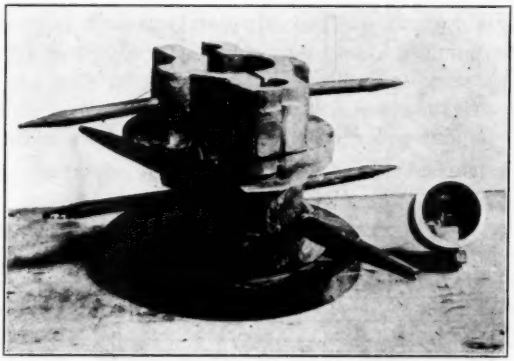

FIG. 3—FRENCH TYPE OF PERMANENT MOLD FOR CASTING ALUMINUM-ALLOY PISTONS; ASSEMBLED (GUILLET)

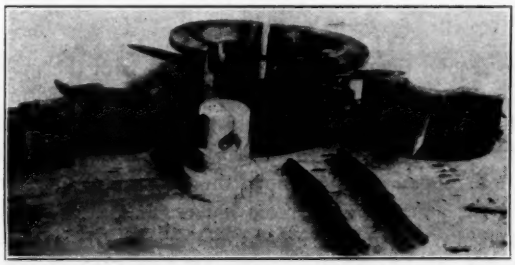

FIG 4—FRENCH TYPE OF PERMANENT MOLD FOR CASTING ALUMINUM-ALLOY PISTONS; DISSEMBLED; CF. FIG. 3 (GUILLET)

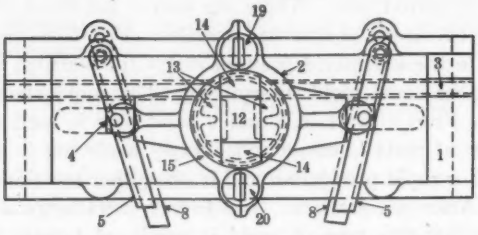

FIG. 5—TOP PLAN OF PERMANENT MOLD FOR CASTING ALUMINUM-ALLOY PISTONS; ENGLISH TYPE (THE METAL INDUSTRY, LONDON)

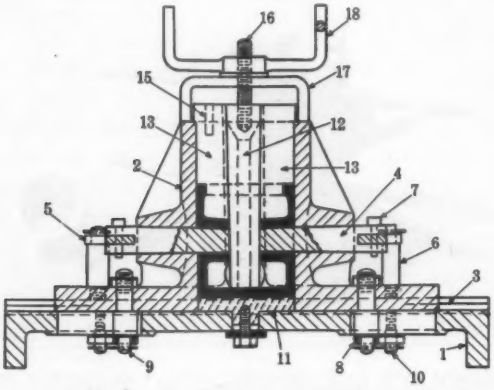

FIG. 6—CROSS SECTION OF PERMANENT MOLD FOR CASTING ALUMINUM-ALLOY PISTONS; ENGLISH TYPE; CF. FIG. 5 (THE METAL INDUSTRY, LONDON)

The second type of mold is arranged with the mold halves slidably mounted upon a base plate, which may form part of the mold cavity or not. The mold halves are held in alignment by means of guides on the mold base and the halves are actuated by levers arranged so as to move the halves together and apart. In this type, generally, the mold halves contain the entire mold cavity and also the gates, runners, and riser. This type of mold is employed considerably in England,[21] and Figs. 5 and 6 show the top plan and cross section of a typical mold. Referring to

the figures, 1 is the base plate, which is grooved along its length to permit the mold halves 2 to slide backward and forward; additonal guide is furnished by the T-shaped feather 3, which is slightly recessed into and screwed to the base. A small dowel is fitted into the halves at any convenient position, and a spigoted plug 11, is screwed to the base; this plug forms the piston head, and the mold halves close up against it. The halves are operated by the levers 8, 8, working on the pivoted round studs 10, which are screwed into the base from below, and on the fulcrum studs 9, screwed to the mold sides and working in slots cut through the base. The pivot and fulcrum studs are provided with split pins in order to prevent the levers from dropping off. The wrist-pin cores 4 are operated with levers 5, through pivot studs 6, screwed to the base, and fulcrum pins 7 running vertically through the ends of the cores. If mechanical operation of the mold halves and cores is undesirable, the levers may be replaced with attachments for operation by hand, using tongs.

The center section of the main core is designated by 12, which is tapered downward on all four sides, while the side core segments are shown by 13, 13 and 14, 14. In operating, after pouring a casting, the center section 12 is removed first, and the segments 13, 13 and 14, 14 removed later. One of the segments 13, 13 should be slotted to accommodate the locating pin 15 which is drawn into a mold half, this being for the purpose of ensuring that the wrist-pin cores shall be concentric with the bosses. The screw 16, bridge pieces 17, and wing nut 18 shown in Fig. 6 are used for loosening the center core piece 12. The pouring gate and riser, which are similar in shape, are shown at 19 and 20. After a casting is poured, the cores 4 are first drawn back, the center section of the main core lifted out, then the other core segments are taken out, and the casting is removed.

A similar type of mold is also employed in England for casting pistons, but in this a sand core is used. Fig. 7 shows such a mold in side cross section, which resembles that in Figs. 5 and 6. The base is designated by 1, the mold halves by 2, the feather guide by 3, the wrist-pin cores by 4, and the spigoted plug for locating the core by 8. In this mold, the piston is cast

with the head up instead of the skirt as in the previous case. The core print for the sand core 5 fits in a recess machined in the plug 8. A loose fitting cast-iron plug 6 forms the head of the piston and also acts as a vent, allowing gas and air to escape on pouring. The eyebolt 7 is used to lift out the plug. The levers for operating the mold halves are not shown in the figure nor are the gates. Small stop pins 9 are used on the wrist-pin cores 4 in order to prevent them from being pushed in too far and thereby breaking the sand core.

It should be emphasized that care must be exercised in designing and building the mechanical actuating arrangement for

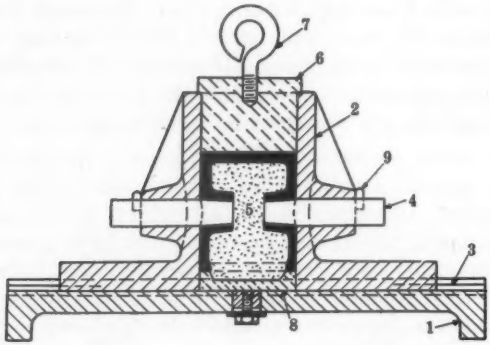

FIG. 7—CROSS SECTION OF PERMANENT MOLD FOR CASTING ALUMINUM-ALLOY PISTONS; ENGLISH TYPE; USED WITH SAND CORE (THE METAL INDUSTRY, LONDON)

these two types of molds, since otherwise the operation will be hindered by binding and sometimes by sticking of the mold halves when heated. However, as explained, the mechanical operation may be dispensed with, and all assembling and movement of parts done by hand.

The third type of mold consists of two mold halves hinged together, so as to part readily, and slidably mounted upon a flat base plate. In this type, the mold cavity and the gates and risers are cut in the halves, the cavity and other cuts being equiaxed with respect to the line of parting. The halves are moved toward or from each other by handles or by pushing the

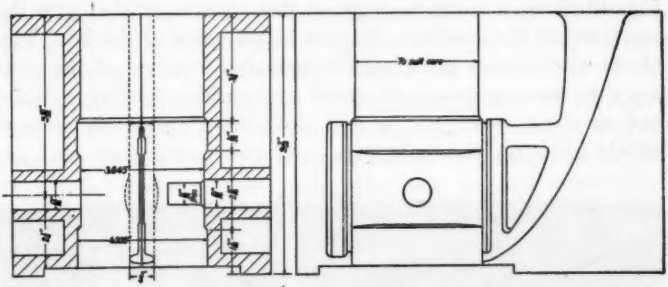

FIG. 8—DETAIL DRAWING OF PERMANENT MOLD FOR CASTING ALUMINUM-ALLOY PISTONS; AMERICAN TYPE

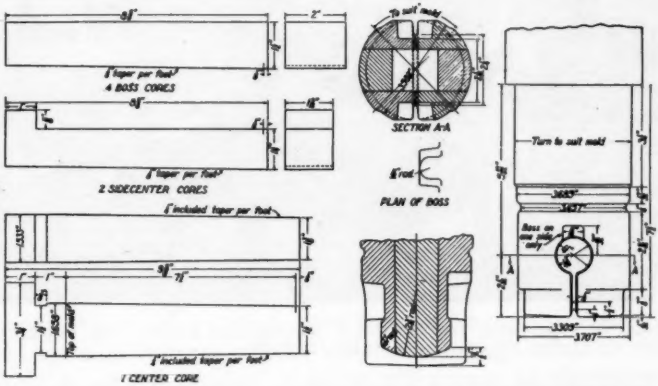

FIG. 9—DETAIL DRAWING OF CORING FOR MOLD SHOWN IN FIG. 8

blocks with tongs or other tools, and the halves are held firmly in position for pouring by a cam lock or other kind of fixture. This type of mold is employed largely in American piston practice and is well adapted for rapid production. Fig. 8 shows a detail drawing of a mold used in American practice for casting 4-in. diameter pistons, and Fig. 9 is a detail drawing of the coring for making the internal cavity in the piston. The drawings are self explanatory and do not require detailed discussion here. The hinges and locking clamp of the mold are not shown.

Fig. 10 shows a complete mold of this type, assembled with the cores, ready for pouring; the cam lock is seen at the left; Fig. 11 shows the same mold opened and after removal of the casting (the pouring-gate and shrink-pad cavities have been limed and so show clearly). In this mold there are seven sections which make up the main core, and two round core pins are

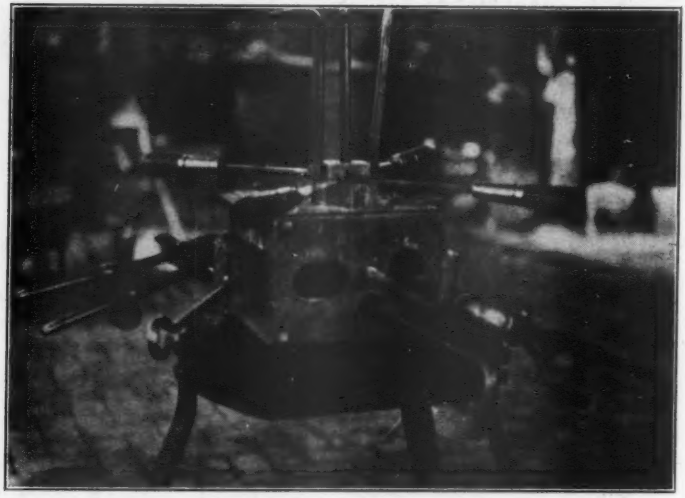

FIG. 10—COMPLETE PISTON MOLD, ASSEMBLED READY FOR POURING, AMERICAN TYPE

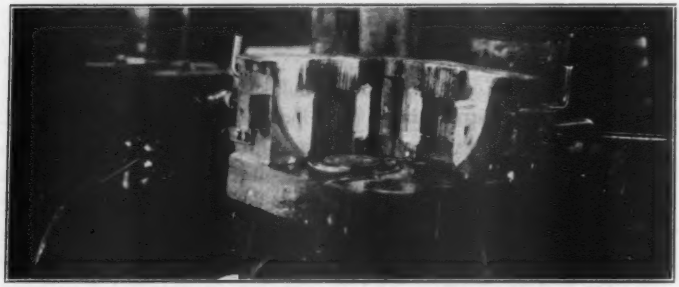

FIG. 11—PISTON MOLD, DISSEMBLED, AND AFTER REMOVAL OF CASTING (CF. FIG. 10)

employed for the wrist-pin holes in the bosses. The mold walls are provided with cavities, as shown in Figs. 8 and 10, into which burners are inserted for heating the mold. The operation of this mold is entirely by hand, but it may be equipped with levers for parting so that it is semi-automatic and may be operated by one man. The operation of this mold will be discussed in detail in later paragraphs, and various methods of gating the same mold in the production of a typical piston casting will be taken up when considering the experimental work in later pages.

As pointed out, either sand or collapsible steel cores are used in piston molds, and the latter are preferable. Methods of coring in the production of pistons will be taken up when considering the design of molds and methods of gating in later paragraphs.

Patented Molds:—Very many patents have been taken out pertaining to the permanent-mold casting of metals and alloys,[30] and more particularly to aluminum-alloy motor pistons. Patents dealing with piston molds describe molds, processes, methods of gating, special constructional features, etc., the patent procedure in most cases consisting of first patenting the process and mold and then following this by separate claims on each detail of the mold and even of the composition of the alloy for casting. While space does not permit the analysis of a typical patent, nor is this necessary since they can be readily consulted, the essential features covered by existing patents relate to the mold proper, the method of gating, the process of permanent-mold casting and more particularly of casting pistons in permanent molds, special cores, special alloys for casting, and metallic and refractory inserts which are alleged to induce even cooling of the alloy after pouring. The numbers of some patents relating to the production of aluminum-alloy pistons in permanent molds are subjoined:

U. S. Pat. No.	Date	U. S. Pat. No.	Date
1,296,588	Mar. 4, 1919	1,296,595	Mar. 4, 1919
1,296,589	Mar. 4, 1919	1,229,596	Mar. 4, 1919
1,296,590	Mar. 4, 1919	1,296,597	Mar. 4, 1919
1,296,591	Mar. 4, 1919	1,308,103	July 1, 1919
1,296,592	Mar. 4, 1919	1,308,156	July 1, 1919
1,296,593	Mar. 4, 1919	1,370,553	Mar. 8, 1921
1,296,594	Mar. 4, 1919	1,420,903	June 27, 1922

Other American, as well as British, patents specify alloys to be used for casting motor pistons.

Materials for Molds and Cores

Materials for Molds:—The material used for the mold body in piston production is usually grey cast iron, although mild steel is satisfactory and has been employed. A great many different compositions of cast irons and steels have been tried, as well as graphite, plaster of paris, and refractory materials; these non-metallic materials are of little importance in permanent-mold work in general and need not be considered here. The operating conditions of permanent molds for casting aluminum alloys are less severe than those of dies in die casting, but chrome-vanadium steel as used for dies is a satisfactory material for molds and gives longer life than grey cast iron. Taken by and large, cast iron is the most satisfactory material for piston molds; it is cheap, easily machined, and fairly long lived. Ordinary run of grey foundry iron has given entirely satisfactory results, but special compositions are recommended, and while they may be better there are no data which show the superiority claimed. Close-grained iron, high in graphitic carbon and low in combined carbon is preferred.

A typical analysis for grey cast iron used for permanent molds is as follows: 0.14 per cent combined carbon, 3.35 graphitic carbon, 2.40 silicon, 0.43 manganese, 0.10 sulphur, and 1.3 per cent phosphorus. May[4] recommends an iron of the following composition: 0.89 per cent combined carbon, 2.76 graphitic carbon, 2.02 silicon, 0.29 manganese, 0.07 sulphur, and 0.89 per cent phosphorus. High phosphorus is regarded as necessary to give fluidity to the iron and to obtain sharp molds when cast. Johnson,[6] however, objects to high phosphorus content on the grounds that the iron-phosphide eutectic has a low melting point, and the repeated contact of liquid alloys has an erosive effect which rapidly ruins the surface of the mold. In the permanent-mold castings of brass, bronze, aluminum bronze, and other copper-rich alloys, the phosphorus content should undoubtedly be low, but this is not essential in molds for aluminum alloys. So far as

is known, great trouble has not been experienced in aluminum-alloy work because of variation in mold composition, but certain compositions of cast iron are undoubtedly better than others.

It should be pointed out, however, that cast-iron molds may grow, warp, and become distorted in service, due to repeated heating and cooling, and such distortion is due to the normal growth of grey iron which occurs on repeated heating, to casting strains, and other factors. The question of growth and distortion in grey iron has been discussed by a number of workers and is summarized in another paper by the writers.[30] Annealing rough molds before machining is beneficial in preventing distortion of the mold while in service. The whole question of materials for permanent molds has not been thoroughly studied, and much remains to be learned in regard to this matter. In general, it may be said that in the case of alloys which do not attack the mold and cores their life is not a function of the number of castings poured but rather of the number of times that the mold is heated and cooled. It is estimated that a mold used continuously will outlast four molds used intermittently. Although grey cast iron is a suitable material for piston molds, there is considerable difficulty in obtaining sound mold castings, and often considerable machining will be done upon a mold when a large number of blowholes will be revealed which spoil the casting.

Materials for Cores:—Metallic cores for permanent molds in aluminum-alloy work are made of mild steel and of alloy steel. The mild steel core is satisfactory and will usually last as long as the mold if handled carefully so as to prevent nicking and marring. In alloy steels, cores are made of tungsten steel of the usual tool grade, of chrome-tungsten steel, and of chrome-vanadium steel. Alloy-steel cores will have considerably longer life than mild-steel cores, but they are, of course, more expensive and difficult to machine. A chrome-vanadium steel suitable for making cores has the following composition: 2.10 per cent chromium, 0.35 vanadium, 0.40 carbon, 0.65 manganese, and 0.10 per cent silicon. Ordinary hard-baked sand cores are employed when a collapsible steel core is not used.

Design and Preparation of Molds, and Methods of Gating

The design of permanent molds for casting motor pistons is very variable depending upon the type of piston and individual preferences of mold designers, and the greatest variations are found in methods of gating. It may be said, by and large, that molds should be made so that their costs of operation and upkeep are small, and hence the design should be as simple as possible. As pointed out above, many complicated types of molds are described in the patent literature and actually used in practice, particularly for pistons, but such complicated molds are totally unnecessary. Molds, and the coring, should be so designed that the molds are readily parted and the cores easily removed, and the gating is of especial importance since many defects can be traced to wrong gating design. Wide divergence of opinion exists as to gating methods—some designers preferring to adhere to simple gates while others adopt bizarre appearring gates which are purported to yield certain especially desired results. Several methods of gating a typical piston will be described later when discussing the experimental work performed in the investigation, while here it is the object of the writers to discuss mold design and gating in its more general aspects without reference to methods of gating specific piston castings.

General Aspects of Design:—Referring first to the size of molds for piston casting, both the size and exterior shape of molds varies with different designers. Molds may be made with round, square, or rectangular cross sections in exterior shape and although mold size is not generally regarded as of great practical importance, it should be governed by certain principles. It is obvious that an extremely light and thin-walled mold will tend to warp more quickly than a heavy mold, while exceedingly bulky molds are unwieldy and slow in operation. A mold should not be so light that the heat is dissipated too rapidly and yet not so heavy that it becomes too hot with successive casts. The desirable size of mold is one of such mass that the heat loss by radiation to the air about compensates for the heat taken up from the liquid alloy on pouring, resulting in a nearly uniform temperature throughout the mold. Irregularities in

temperature can be taken care of by intermittent heating with burners. The mold shown in Fig. 8 is a fair design. It is desirable to have a uniform simple shape for the exterior of the mold, and the cavity for the casting is preferably equiaxed with respect to the mold mass and line of parting so that heat dissipation by radiation, or heat input from burners, takes place evenly in all parts of the mold.

It is worthy of especial notice at this point to state that the problem of heat distribution in a mold is of great importance as related to the quality of the castings produced, and this must be taken into consideration when designing the mold. The question of mold temperatures will be discussed later when dealing with mold operation, but here it is important to point out that the question of heat distribution must be given careful study in the original design of the mold. As liquid alloy is poured into the mold, the heat is, of course, transmitted to the mold, causing it to become hotter with successive pours. If the mold becomes too hot, as it is liable to if excessively thick, the rate of production is reduced, and the favorable effect of chilling is lost. In practice, cooling of the mold and maintenance of proper temperatures are taken care of by radiation losses of heat and by applying external heat as required. Water-cooled molds are not employed. In the matter of heat distribution, some molds are made with special inserts of greater or less heat conductivity than the mold proper in order to cause faster or slower transfer of heat from particular sections and thus equalize the rate of freezing and cooling throughout the mass of the casting. Thus when making castings such as motor pistons having thick and thin juxtaposed sections, it is desirable to make some provision for having such sections freeze at about the same rate, since otherwise cracking will likely occur at the juncture of the sections. In such a case, copper or other inserts of greater heat conductivity than the cast iron of the mold may be placed adjacent to the heavy sections and thus increase the rate of freezing of those sections.

Permanent-mold castings can be made to close size tolerances, and the usual tolerance for aluminum-alloy castings is

±0.010 inch. In designing piston molds, allowance must, of course, be made for the contraction of the alloy on freezing and cooling, and the usual allowance for pistons cast in 90:10 aluminum-copper alloy is 0.10 per cent. Exact allowances for different alloys should be determined by experimental measurement of the contraction as in the case of sand-casting practice, as has been emphasized by one of the writers,[28] but when new designs are put into production the exact size of the mold cavity can be arrived at only by trial and with a given method of gating. Hence, it is best to cut the cavity too shallow and then enlarge it later as required by the resultant dimensions of the casting.

In most types of permanent molds, ejector pins for removal of the frozen castings, are not provided, but the castings are loosened by hand using small tongs. Castings may often stick to the mold wall in one of the halves when the mold is parted, particularly if the mold walls are rough, and such sticking may be avoided, breakage of the castings on removal prevented, and extraction facilitated by the employment of ejector pins. Recently, ejector pins have been used on one-man semi-automatic molds and have been found quite satisfactory. Ejectors can be easily applied to ordinary molds by inserting small push rods through the mold walls.

Cores should preferably be made of steel, and the disadvantages of the sand core will be taken up in later paragraphs.

Gating of Molds:—In addition to the mold cavity formed by the walls of the mold halves and by the inserted cores, gates, risers, feeders, vents, etc., must be cut in the mold. In order to minimize the amount of scrap produced in the form of gates, risers, feeders, etc., it is desirable to make these parts as small as is consistent with the production of sound castings. As pointed out above, methods of gating pistons and other permanent-mold castings are very variable in practice, and no specific rules can be laid down to define the type or size of gates or where these should be attached to the casting. Various elaborate pouring gates containing traps, shrink balls, and blind risers, and formed with strange curves are depicted in patents on piston molds, but such gates are wholly unnecessary. It is

much better practice to employ the simplest form of pouring gate possible, since such a gate fills all requirements and is easily cut in the mold halves. The method of gating, both as to pouring gates and feeders, and the mode of introducing the liquid alloy into the mold is of the greatest importance, and common defects can be traced to wrong gating and uneven rise of the liquid alloy in the mold as well as agitation and splashing of the alloy.

There are four main items for consideration in designing a pouring gate; viz., (1) the size and cross section of the gate; (2) the point of attachment of the gate to the casting; (3) the pitch of the gate or angle of inclination from the vertical; and (4) the size and shape of the feed opening or choke. These items are taken up *in seriatim* below, and the question of feeders, shrink pads, risers, and vents are considered in later paragraphs.

Referring to the first item; pouring gates are made of varying height and cross section, depending upon the views of designers as to the requirements, and such gates may be circular or oval in cross section and from about ¾ to 2 inches in largest cross-section dimension. Gates are normally tapered downward, and a typical oval gate is ¾ x 1½ inches at the top and ¾ x ¾ inch at the point where it attaches to the mold. A typical gate of circular cross section is 2 inches in diameter at the top and ¾ inch at the bottom. The length of gates is variable, depending upon the angle of pitch and the configuration, but ordinary gates are 6 to 10 inches in total length for a 4-inch piston casting.

Referring to the second item; there is considerable difference of opinion as to where and just how the pouring gate should attach to the casting, and piston molds are gated at the bottom of the casting, along the side from top to bottom or at intermediate points, and at the top. Some gates are designed so as to feed bottom, side, and top. It might seem, off hand, as though a gate feeding from the bottom and allowing the liquid to rise gradually upward through the mold would be desirable, and this method of gating is employed commercially.

However, since the alloy is chilled considerably on coming in contact with the mold, the portion of liquid alloy first entering the mold forms a skin where it strikes the mold, becomes sluggish in its flow (at ordinary pouring temperatures), and retards filling of the mold. Or, better stated, under this condition, the liquid alloy tends to rise faster than normally in the heavier sections, resulting in poorly controlled flow of alloy throughout the mold cavity. It is quite obvious that a gate which feeds the bottom of the mold cavity first and also feeds the casting along the vertical wall (skirt of the piston, when casting in the inverted position) is theoretically better at least, since such gating does not disturb the skin of semi-liquid alloy on the bottom of the mold. Gates are best attached to a heavy section where possible, and a shrink pad may be added to another heavy section so as to ensure proper feeding of the whole body of the casting.

Referring to the third item, viz., the pitch of the gate; the pouring gate should be arranged at a suitable angle with relation to the casting, and this angle is 30 degrees to 60 degrees with the horizontal in actual molds. If the gate is vertical, or nearly so, and attached to the bottom by a sharply rounded fillet section, there is danger of the alloy splashing when it strikes the bottom, and this is undesirable. On the other hand, if the angle of the gate is very acute with reference to a horizontal line through the bottom of the mold, then there is a tendency for the liquid alloy on being poured to shoot up the opposite side of the mold cavity. A pouring gate with a moderate angle of pitch is best, and the writers prefer gates set at 30 degrees to 45 degrees, depending upon their size and the size of the choke.

In the matter of the fourth item, i.e., the choke or size of feeder section from the gate to the casting; the choke opening should be adjusted as to size depending upon the size of piston being cast—larger pistons requiring larger choke openings. Suitable size of choke for 4-inch diameter pistons is 5/16-3/8 inch, and this applies to the choke from the bottom pouring gate and from the side shrink pads. With some gates no choke

is employed. The choke opening should be shaped so as to give a spreading feed. In practice, the most suitable size of pouring gate, angle of pitch, and size of choke can be best determined by trial; the size of feeder cavities should be cut too small in the original mold and then increased gradually as conditions seem to require.

In connection with gating methods, the questions of size, shape, and location of shrink pads and risers are of importance. For the purpose of the present discussion, a riser will be regarded as a feeder attachment with egress to the top of the mold so that liquid alloy may flow through it and over the top surface of the mold, i.e., the riser-hole opening is on a level with the pouring-gate-hole opening. A shrink pad is defined as a blind riser and combined feeder, gated to the side wall of the piston and having no egress to the upper surface of the mold. Fig. 27 shows a casting with thin risers attached to the tops of shrink pads, while Fig. 28 shows one with side shrink pads and no risers.

There is considerable difference of opinion as to whether risers or shrink pads should be used and as to where they should be placed. In the French mold shown in Figs. 3 and 4, the riser is a heavy sink head attached to the end of the skirt, the piston being cast in the inverted position; while in the English mold shown in Figs. 5 and 6, the riser is of the same shape and dimensions as the pouring gate and placed diametrically opposite. In the American mold shown in Figs. 8 and 11, no riser is used but a heavy shrink pad is gated to the piston skirt at a point diametrically opposite the pouring gate and another pad is an integral part of this gate. Many methods of attaching risers and shrink pads are in use, and in some cases, in the American type of mold, the shrink pad opposite the pouring gate is left off, apparently without harmful results. The casting of pistons without shrink pads on the side opposite the gate would eliminate some scrap. While a shrink pad is used primarily for the purpose of feeding liquid alloy to the casting, just as a riser is used in sand practice, it has a secondary function; viz., it undoubtedly aids, in regulating the flow of

liquid alloy upwards, as to rate and uniformity. The size and shape of shrink-pad feeders vary considerably, although the value of the shrink pad depends primarily on the operation of the feeder. If the feeder freezes before the adjacent piston wall, the shrink pad is rendered useless. Either risers or feeders are regarded as necessary in piston casting, and their size and location are best determined by trial.

Coring:—While both sand cores and collapsible steel cores are employed in practice, the latter are preferable, although for pistons of intricate design such difficulties are encountered that a sand or other destructible core must be employed. Wherever possible, where the expense is not too great, and where a core with not more than seven or eight pieces can be employed, a steel core should be used. The sand core gives a rough surface finish to the interior of the piston casting, and causes unequal cooling of the casting. Steel cores usually consist of from three to nine separate pieces. Some designs of pistons could be readily produced with a three-piece core were it not for a small lip protuberance on the inside of the skirt, and coring could be much simplified if piston design were not so complicated.

When it is impossible to cast pistons using a collapsible steel core owing to the design or because too many core pieces would be required, a sand core must be resorted to. It should be borne in mind that when sand cores are employed one or more core prints are necessary in order to properly support and locate the core and that these prints must register with recesses in the mold. Moreover, great care is required in inserting them in the mold and they must be heated before being placed. The proper alignment of sand cores in iron piston molds presents considerable difficulty, but steel cores can be very accurately fitted and are much easier to manipulate in production.

Figs. 12, 13 and 14 show methods of coring three different designs of piston castings, where three-, five-, and seven-piece cores, respectively, are required. The figures are self-explanatory. The center piece of a built-up collapsible core should always be tapered slightly so as to permit rapid withdrawal,

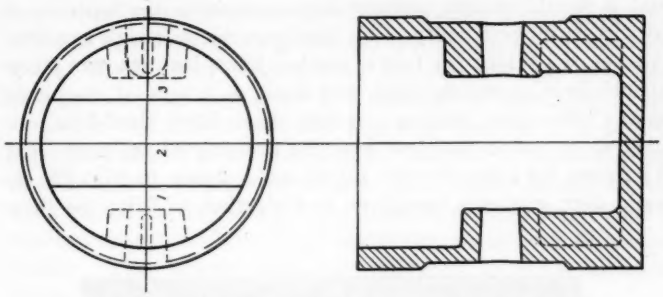

FIG. 12—METHOD OF CORING WITH THREE-PIECE CORE

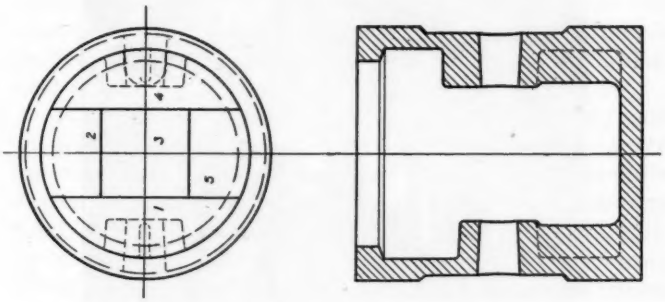

FIG. 13—METHOD OF CORING WITH FIVE-PIECE CORE

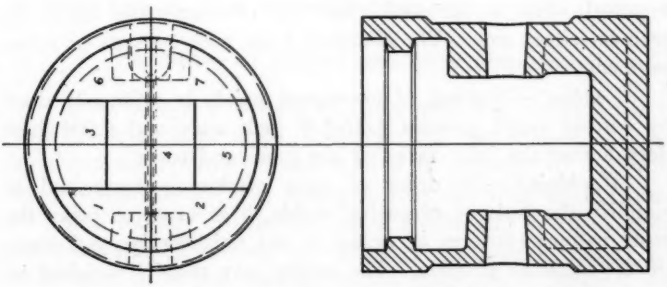

FIG. 14—METHOD OF CORING WITH SEVEN-PIECE CORE

and it should possess considerable mass above the taper so as to withstand wear and possible breakage due to rough handling. A taper of 1/8 inch per foot is ample. Joints between core pieces should have a smooth finish and show no traces of machining marks other than venting grooves; these latter should be situated so as not to interfere with the drawing of the core. Fig. 15 shows the cores for the piston mold shown in Fig. 10; the main core segments have been tied together to form the shape

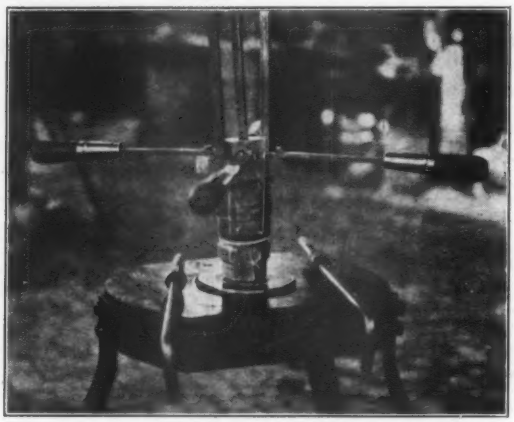

FIG. 15—CORES FOR A PISTON MOLD (CF. FIG. 10)

assumed when in the mold, and the two wrist-pin cores are seen on either side. The complete main core consists of seven segments.

Venting:—Venting of permanent molds is ordinarily done by cutting small grooves 1/16-1/8 inch wide and 0.004 inch deep across the joint faces of the mold and cores.

Machining:—In order to save machining costs and to simplify the task of preparing molds, it is usual to make the mold pattern conform as nearly to the finished size and shape of the mold as possible. The cavity may then be finished by a small amount of machining. Gate and feeder cavities are

not normally cast in the mold but are machined out as required. When a new mold is being put into production, the mold cavity, gates, shrink pads, feeders, etc., are cut sparingly and then enlarged later as required. It is difficult to determine in advance the best size of gate and feeder cavities, and it is accordingly desirable to make them smaller than seems actually necessary and then enlarge them later. The inside surface of the mold should be very smooth and show no traces of tool marks; castings tend to stick to rough molds and are difficult to remove readily. The writers feel that it is best to polish the mold cavity and core surfaces.

Mold Fittings:—The design of mold fittings, including hinges, locks, handles, etc., is more or less arbitrary. It is advisable to provide freely working hinges and a lock or mold clamp that operates easily and holds the mold halves firmly in position. Wrought iron, or mild steel, is suitable for making mold fittings.

Mold Mountings:—Methods for mounting piston molds are arbitrary, but a suitable mounting may be made by attaching iron legs to the cast base plate so that the mold when placed thereon is about waist high. The base plate should be sufficiently large, in the case of a slidably mounted mold, so that the mold can be pushed around over a moderate area without falling off. In order to prevent too rapid loss of heat through the bottom of the mold, the base plate may be insulated with asbestos. Mold mounts may be conveniently arranged in a battery of several, so that the pouring for a number of molds can be taken care of from one holding pot.

Production of Pistons, and Mold Operation

The essential principles of permanent-mold operation have been discussed in previous paragraphs and also in another paper by the present writers,[30] and here it is desirable to deal with the processes involved in casting pistons and with the operation of piston molds. No definite rules can be laid down to cover the most suitable method of operation of molds to ensure the production of sound castings with a minimum of wasters, but given a proper design of casting and mold and a suitable

method of gating, the most important factors affecting production are the following: viz., (1) composition of the alloy used; (2) temperature of pouring; (3) temperature of the mold and cores; and (4) speed of operation. The first item will be discussed in the next section of the paper, and the last three will be considered in later paragraphs in the present section. In discussing piston production here and the variables affecting the occurrence of defects, reference is had to molds cored with collapsible steel cores and not with sand cores. The introduction of the sand core affects the variables and introduces complications which will not be considered in the present paper. Moreover, reference is had here to cast-iron molds not lined with a refractory coating or wash. The permanent-type mold with a thin refractory lining covered by a layer of freshly deposited amorphous carbon as used by the Holley Carburetor Co.[29] for the production of cast-iron carburetors, and by the Ford Motor Co. for the production of cast-iron pistons may have application in the aluminum-alloy field, but this can not be considered here.

Melting and Casting:—In melting, the aluminum-alloy is ordinarily first made up in an alloying furnace of any suitable type and then transferred in the liquid state to small holding furnaces or pots situated near the molds. The holding furnace may be either of the stationary-crucible or iron-pot type, and the temperature of the alloy is maintained by burners. For casting, the alloy is simply ladled from the holding pot with small iron dippers and poured into the molds. The alloy enters the mold under the force of gravity and is put in by pouring as in ordinary sand practice.

Operation of Piston Molds:—Before starting to pour piston castings in a mold such as shown in Figs. 10 and 11, the mold is first pre-heated to 325-500 degrees Cent., depending upon the casting to be made and the design of the mold. In American practice, this heating is accomplished externally by projecting flames from gas burners against the outside walls of the mold halves on either side. The outside walls of the mold halves are recessed as shown in Fig. 8, and the burner flames are projected in the recess cavities. Discussion of the

operation of piston molds here will be confined to the American type of mold. The mold shown in Figs. 10 and 11 is operated by two men—a molder and a helper.

In the operation of producing piston castings, the molder dips the liquid alloy from the holding pot, pours it into the mold, and then returns the dipper to the top of the holding pot in order to keep it hot. This operation requires about 10 seconds, depending upon the dexterity of the molder. Usually a few castings must be poured into a heated mold before the proper working temperature is obtained, and the operation of casting is proceeding regularly. The actual time of pouring is 1/2-3 seconds. While the molder is returning the pouring dipper to the top of the pot, the helper removes the core pin or wrist-pin core on his side of the mold and lifts out the center section of the main core. Then, the helper lifts out the back core sections and the molder removes two side core sections as does the helper. The molder then unlocks the mold, and both molder and helper part the halves. Next, the molder removes the casting and makes rough inspection, while the helper cleans off the cavity, brushing out all chips or alloy adhering to the mold. As explained, Fig. 10 shows a mold assembled and ready for pouring, and Fig. 11 shows the same mold after being dissembled and the casting removed. The operation of pouring castings proceeds at an arbitrary rate, depending upon the working qualities of the mold and the pouring temperature of the alloy. The object in view is to operate the mold at such speed that a nearly uniform temperature obtains with successive casts. Individual molds, depending upon the size, operate best at particular temperatures, and it is sometimes necessary to keep the burner flames going during a run, i.e., when using the interrupted pouring system.

After removal of the casting and cleaning the mold, the molder and helper then close the mold and lock it and replace the cores in an order reversed from that in which they were removed. In casting an ordinary 4-in. diameter motor piston, the entire operation requires 60-75 seconds, and the piston casting actually remains in the mold for 25-35 seconds after being poured. Two men can cast from 250 to 400 pistons in a 9-hour

day, depending upon conditions. Molds may be difficult of operation because of poorly designed hinges and locks, because of the draft, or because of many cores which must be placed, and the removal of castings usually takes longer than from dies in die casting. In one-man molds various mechanical devices are employed for opening and closing the mold and ejecting the castings, but in both ordinary and one-man molds the cores are set by hand.

As mentioned, the pistons are inspected while hot on removal from the mold, and all defective castings, together with broken gates, splashings, etc., are returned to the melting furnace. After cooling, the castings which have passed the hot inspection are sent to the band saw where the gates and risers are cut off, and then the castings are ground smooth on a grinding wheel. Each lot of pistons is then inspected cold and weighed, and then sent to the machine shop.

Pouring Temperatures:—In general, pistons cast in aluminum alloys are poured at as low a temperature as is consistent with the alloy filling the mold and avoiding cold shuts and internal holes. The pouring temperature for permanent-mold-cast aluminum alloys is very important not only as regards the physical properties of the casting but also as regards the occurrence of defects therein. The temperature to be employed depends upon the melting point of the alloy, the temperature of the mold, and the design of the piston and method of gating. The ordinary pouring temperature for 90:10 aluminum-copper alloy is 725-775 degrees Cent., depending upon conditions. Experiments made by the writers have shown that pouring at 25-50 degrees Cent. higher tends to eliminate internal holes caused by uneven flow of the alloy and also of blowholes due to gas occlusion. The flow of liquid alloy is more rapid in heavy sections than in light ones owing to the chilling effect of the mold, and the flow of alloy as affected by pouring temperature can be conveniently examined by pouring series of piston castings in which for a given pouring temperature six or so castings are made by partly filling the mold. Thus, Fig. 16 shows a set of castings so poured. The chilling effect on an alloy poured at higher temperatures would be less than at lower

temperatures, and it will be noted from the figure that the alloy rises through the heavy sections to a greater height than through the light ones, thus causing overlaps on the slower flowing alloy in the light sections and forming cavities or cold shuts. Such a cavity, which may often be caused by entrapped air or gas, is compressed into smaller volume by additional alloy, and, when the piston is filled, is pushed upward by the flow of alloy. It is of more than passing interest to state that such cavities can be chased up the skirt of a piston casting, in some cases, by increasing the pouring temperature.

Although a fairly high pouring temperature is desirable for the reasons just pointed out, cracks are more likely than in castings poured at lower temperature, and internal contraction

FIG. 16—PARTLY FILLED PISTON CASTINGS, SHOWING UNEVEN FLOW OF ALLOY; POURED UNDER OPERATING CONDITIONS

cavities and draws are more numerous. The effect of pouring temperature upon the contraction of aluminum alloys when poured in sand molds and graphite molds has been discussed by one of the writers[28] (*quo vide*). The mold temperature is important as affecting the required pouring temperature, and this is considered below.

Mold and Core Temperatures:—Ordinarily, before starting to pour pistons in permanent molds, the mold must be heated for 2-4 hours, and in practice this is usually done by lighting the burners at 4:00 A.M. so that the molds will be sufficiently hot when the force starts work at 8:00 A.M. The mold is heated externally by gas burners as explained, and while the question of mold and core temperatures is exceedingly important, the devices in use for heating are usually rather crude

and do not insure uniformity of temperature. In piston practice, molds are operated at 325 degrees to 525 degrees Cent., depending upon conditions, and cores are normally kept cooler than the mold proper. In general, the best temperature is 300-400 degrees Cent.; this gives a sufficiently rapid chilling effect and is still sufficiently hot to allow free flow of the alloy. Even distribution of temperature throughout the mold walls is important and helps to ensure uniform flow of alloy within the limits imposed by section sizes. While it might be expected that the temperature in various sections of a mold would tend to become the same with successive casts, this does not always follow, and in some molds the writers have found by measurements that the temperature variations become greater. A num-

FIG. 17—VARIATION IN FLOW OF ALLOY IN PARTLY FILLED PISTON MOLD; ONE MOLD HALF HEATED HIGHER THAN THE OTHER

ber of factors affect the maintenance of uniform mold temperatures, and of these the most important are: (1) temperature of cores; (2) speed of operation; (3) method of heating; and (4) design of the mold, with respect to heat losses by radiation. The effect of variation in temperature of mold walls on the flow of liquid alloy in piston molds is shown very nicely by Fig. 17; the rise of alloy is higher, as would be expected, on the side highest in temperature. In a number of tests made to examine the effect of temperature variation on flow of alloy, one side of the mold was heated to a higher temperature than the other, and then a series of partly filled molds was poured.

In practice, after an operator becomes familiar with the peculiarities of a given mold, he can regulate its temperature by speed of operation and by the use of externally applied heat. Ordinarily, cores are cooled periodically by dipping in cold

water so as to keep their temperature well below that of the mold proper.

Washes and Coatings:—Washes and coatings for the inside of mold cavities and for core surfaces are not necessary, but in practice a number of different dressings are employed. Such washes as linseed oil, tallow, and a mixture of lime and sodium silicate are used; the latter mixture is made into a thin paint with water and painted on the mold-cavity surfaces. The employment of a suitable coating on the gate and runner cavities is desirable. An insulating coating made of lime and sodium silicate or of fire clay and sodium silicate reduces the heat loss from the liquid alloy in the gates through the mold body, thereby ensuring that these portions remain liquid until after the casting has frozen.

Casting Losses and Defects:—The question of casting losses and defects in pistons can be considered only very briefly and in a general way here, but in a later paper by the writers it will be dealt with in detail. The normal casting loss in piston production is rather high, and the more usual defects causing losses include shrinkage holes, blowholes, cracks, holes due to entrapped air, rough surfaces, inclusions, and overlaps due to the meeting of liquid alloy in its flow in the mold. Defects causing casting losses are not easy to control in piston production because of the large number of variables encountered. The most important factors governing losses include the following: viz., (1) composition of the alloy used; (2) melting temperature; (3) pouring temperature; (4) method of gating, and mechanical variables in the mold itself; (5) method of coring; (6) temperature of the mold and cores, and variation in temperature in different parts of the mold; (7) speed of pouring; and (8) various operating irregularities, e.g., interrupted pouring. Certain of these variables are easily controllable but others only with much difficulty, if at all.

Blowholes and other internal holes in pistons are the most common of the defects mentioned above and the most troublesome to eliminate. While the surface skin of a permanent-mold-cast piston is normally good, the castings require machining, and such machining reveals blowholes that may be present. In

the same way, overlaps, shrinkage holes, and air holes are revealed. Cracks often occur at the juncture of juxtaposed thin and thick sections, e.g., at the juncture of the bosses and skirt, and inclusions are encountered as in sand casting. Permanent-mold-cast pistons are normally sound as to their general mass, and isolated holes are more common than general porosity; the latter is rarely encountered in properly cast pistons. Internal draws or shrinkage holes are due to excessive contraction and lack of suitable feeding, and these can be eliminated. Air holes, due to the entrapping of air by the flow of alloy in the mold, can be eliminated by proper pouring and gating. Actual blowholes, due to gas given off on freezing, are eliminated with difficulty, but their occurrence can be reduced to a minimum by proper melting practice and suitable pouring temperature; the addition of vents may help at times. Overlaps, due to the meeting of liquid alloy, can be controlled by suitable gating practice, and often can be eliminated by increasing the pouring temperature. Cracks can be overcome by employing the proper pouring temperature and by the use of inserts at the proper position in the mold. Inserts when used in permanent molds are ordinarily employed for the same purpose, and serve the same function, as chills in sand molds. Inclusions due to dirty melting practice can be readily eliminated, and rough surfaces which are ordinarily due to poorly machined molds can be easily avoided.

Some typical defects found in pistons are shown in Figs. 18 to 20 inclusive. Fig. 18 shows a rough bottom of a piston, caused by an improperly cleaned and rough mold. Fig. 19 shows a small hole in the top of a wrist-pin boss. Fig. 20 shows two blowholes in the skirt of a semi-machined piston.

Aluminum Alloys Used for Motor Pistons

The composition of aluminum alloys to be used for motor pistons is important not only from the point of view of the casting qualities but also from the point of view of mechanical properties, thermal conductivity, and wearing qualities. It is necessary that the alloy have good casting qualities, and it must also possess certain physical properties, particularly good strength

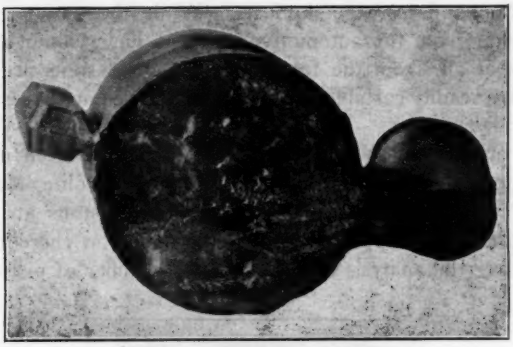

FIG. 18—ROUGH BOTTOM ON A PISTON CASTING

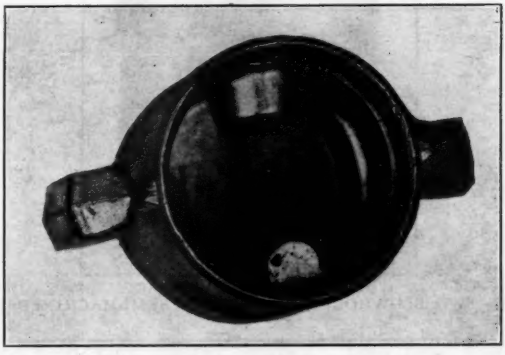

FIG. 19—SMALL HOLE IN WRIST-PIN BOSS OF A PISTON CASTING

at elevated temperatures. The first pistons made were cast in ordinary aluminum alloys, in sand, and after the pattern of the cast-iron piston. Consequently, these pistons were not satisfactory, slap and seizure troubles being usual, as well as distortion, in operation. At the present time, special alloys are employed for pistons and special designs have been worked out taking into consideration the high thermal expansion of the alloys, and aluminum-alloy pistons that give satisfactory mechanical performance in motors are now made in regular

production and in large numbers. While the question of piston design from the automotive point of view cannot be taken up here at all, from the foundry viewpoint designs are desired which are readily castable and which do not require excessive and complicated coring.

A number of special aluminum alloys have been marketed as piston alloys under such trade names as Aerolite, Magnalite, Lynite, etc., but at the present time most pistons are cast in 90:10 aluminum-copper alloy or a modification thereof. Pannell[19] gives the analysis in Table 1 for a number of piston alloys

FIG. 20—TWO BLOWHOLES IN SKIRT OF SEMI-MACHINED PISTON

which have been used. Various patents have been issued for piston alloys, but these need not be cited here.

Referring to the casting properties of aluminum alloys for use in making permanent-mold pistons, the requirements are substantially the same as in sand casting and die casting. The alloy should be well fluid at the normal casting temperature, and high-iron alloys are consequently barred since increasing amounts of iron markedly increase the viscosity of the alloys. Alloys which attack the mold and cores least are desirable, and zinc-bearing alloys are consequently ruled out. Alloys which are the least hot short and which possess low contraction are desirable. Certain alloys seems to dissolve more gas than

others on melting and to give normally less sound castings than others, and both from the point of view of casting and of mechanical properties, alloys which cast soundly are desirable.

Referring to the mechanical properties desirable in a piston alloy, the principal requirement is that the strength should not fall off too much at elevated temperatures. It is also desirable, particularly for aviation-engine pistons, that the alloy should not pit or erode. The temperature attained by the head of a piston operating in a motor is not known precisely, but it can not be much above 300 degrees Cent., on the basis of

Table 1

*Analyses of some piston alloys.**

Name or source	Chemical composition, elements per cent							
	Al	Cu	Fe	Mg	Mn	Ni	Sn	Zn
Corbin	87.5	12.5	...	...	...	...	...	...
Belgium	90.5	7.0	...	...	...	...	...	2.5
German	93	...	...	7	...	...	...	...
Curtiss	95.2	2.5	...	1.5	...	...	...	...
Aerolite	86	12	...	...	2	...	...	...
Air board	89	10	...	...	...	...	1	...
Air board	88	12	...	...	...	...	...	...
Air board	85	14	...	...	1	...	...	...
Benz aviatik	80	6	1.5	tr	tr	...	...	12
British	94.8	...	...	...	...	5.5	...	...
Magnalite	94.2	2.5	...	1.3	...	1.5	...	0.5
Magnalium	95	...	...	5	...	...	...	...
N. P. L.	92.5	4	...	1.5	...	2	...	...
Lynite	88	10	1.5	...	0.25	...	...	...
Lynite	90	8	1.5	0.5	...	...	...	...
Lynite	88.5	10	1.5	0.5	...	...	...	...

*Pannell.

theoretical calculations, so that alloys which are fairly strong at 250-300 degrees Cent. are preferred. The temperature attained depends upon the efficiency of lubrication, the rate of speed, the design of the piston, and the characteristics of the fuel burned. Considerable experimental work has been done in England in the development of special aluminum alloys for use at elevated temperatures and under the conditions encountered in motors, and it has been found that some alloys maintain their strength up to 250 degrees Cent. much better than others. Aluminum-zinc and aluminum-copper-zinc alloys fall off in strength very markedly at only slightly elevated temperatures[2] and are quite useless as piston alloys. The 90:10 and 88:12 aluminum-copper alloys have been found fairly satisfactory for pistons, and in developing special alloys the prop-

erties secured may be compared with those of these binary alloys as a check in performance. The tensile strength of the 88:12 aluminum-copper alloy is about 21,000 pounds per square inch at 20 degrees Cent., 15,000 pounds at 200 degrees Cent., and 10,000 pounds at 350 degrees Cent. The addition of 1-3 per cent nickel to aluminum-copper alloys containing 8-12 per cent copper very markedly improves the strength of these alloys in the cold, and although the strength falls off appreciably with increasing temperature, at 250 degrees Cent. it is still substantially higher than that of the corresponding alloys without

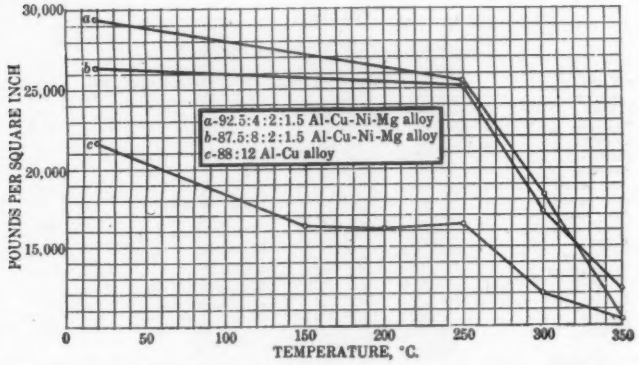

FIG. 21—TENSILE STRENGTH OF THREE ALUMINUM ALLOYS AS AFFECTED BY TEMPERATURE; PLOTTED FROM DATA OBTAINED BY THE LIGHT ALLOYS SUB-COMMITTEE

nickel. Manganese in amount of 1-5 per cent when added to aluminum-copper alloys containing 8-14 per cent copper has the effect of increasing the strength at elevated temperatures. The strength of the 86:12:2 aluminum-copper-nickel and of the 85:14:1 aluminum-copper-manganese alloys is about 22,400 pounds per square inch at 250 degrees Cent. A number of figures for the strength of aluminum alloys at high temperatures have been given in the Reports of the Light Alloys Sub-Committee.[15] Manganese impairs the casting qualities of aluminum-copper alloys since it increases the contraction. Fig. 21 shows the effect of temperature on the tensile strength of three aluminum alloys.

The question of the thermal conductivity of aluminum alloys used for pistons is important, and although the conductivity of the various alloys does not differ greatly, it is doubtless better to employ an alloy with the highest thermal conductivity, other factors being the same.

Aitchison [31], in an important paper, has recently discussed the requirements of aluminum alloys for motor pistons, and reference may be made to his paper for detailed information.

Heat Treatment of Aluminum-Alloy Pistons

When a light aluminum alloy is heated, it first expands, as do most metals and alloys, and the expansion is large owing to the high thermal expansion of the alloys. The coefficient of thermal expansion of the light aluminum alloys varies between 22×10^{-6} and 27×10^{-6}, depending upon the composition; that of the 88:12 aluminum-copper alloy is 26.4×10^{-6}. When an ordinary aluminum-alloy piston is heated, it expands regularly until a temperature of 250-260 degrees Cent. is reached, when the increase in size becomes slightly more rapid and continues for some time even though the temperature remains constant. That is, the piston increases in size some little more than would be expected from consideration of the normal thermal expansion, and this increase is known as growth. When a piston, so heated, is cooled to the ordinary temperature, it will be measurably larger in size than before heating. The phenomenon is known as permanent growth. At the same time, an aluminum-alloy piston, so heated, may change in shape and become warped or distorted, owing to the release of casting strains, and this phenomenon is known as distortion.

The amount of growth on the head of a 4-inch diameter piston may be about 0.004 inch, and the distortion may be also about as much or it may be so large that the piston becomes oval in cross section. Permanent growth is a definite property of aluminum alloys, while distortion is owing to the release of casting strains. When an aluminum-alloy piston which is internally stressed is exposed to the heat and vibration of a motor during running, there is a pronounced tendency for the internal strains, which have not been released by ma-

chining, to be set free, with the result that the piston becomes distorted from its machined shape. Hence, because of permanent growth and distortion, motor pistons may bind on working since they will be too tight at running temperature unless suitable initial clearance has been provided. Of course, it should be stated that the actual growth of a light aluminum-alloy piston under operating conditions in an engine will be less than the ordinary thermal expansion, but in making calculations for piston clearance it is necessary to take into account both the thermal expansion and growth—as well as distortion. Casting strains, and the resultant distortion which they cause, can be removed by simply heating pistons to 400-425 degrees Cent. and allowing them to cool slowly. By such heating, permanent growth will be conferred. Prior heat treatment is advantageous in removing any difficulties which may be caused by growth and distortion and thus permit the employment of closer clearances. So far, heat treatment has not been employed widely in the production of aluminum-alloy pistons, but heating for the removal of casting strains, thereby eliminating distortion, and for causing permanent growth is to be recommended. It should be added that pistons should be heat treated before machining, since if machined before heat treatment, the removal of layers from the piston wall will release stresses and cause some distortion, and heating will cause growth and further distortion, thereby necessitating re-machining or grinding.

It is of rather more than passing interest to point out that Rosenhain, Archbutt, and Wells[25] have shown recently that there are enormous possibilities in the quenching heat treatment of chill-cast "Y" alloy (92.5:4:1.5:2 aluminum-copper-magnesium-nickel), and there is little doubt but that heat treatment may be employed to advantage in the production of aluminum-alloy pistons of better mechanical properties than those ordinarily used.

Machining of Pistons

The machining of aluminum pistons will be discussed briefly here since the question of machining is related to casting losses and piston design and also to motor performance. Piston blanks which are sound may be ruined by improper and

inaccurate machining. Ordinarily, much precise machine-tool work is required in the production of permanent-mold-cast pistons, and the typical operations may be described. Some papers have appeared dealing with the subject.[12, 13, 14]. In the matter of machining, it is important to point out that if the advantages of the aluminum-alloy piston are not to be lost, the machine-tool work must be precise, and it is of the utmost importance to secure parallel alignment of the wrist-pin hole with the head of the piston as well as squareness with the vertical axis. Misalignment usually results in wearing away of one side of the piston and loss of compression, if it does not cause oil pumping. The machining operations given below are those used in the plant of the piston manufacturer.

After the rough piston blanks from the permanent molds have been freed of gates and rough ground, the first operation consists in boring and facing the skirt. This is done on a Porter Cable production lathe, equipped with an automatic back facing attachment and longitudinal feed traverse, the piston being held in a Barker wrenchless chuck. The lathe provides for alignment of the circumference of the piston with its longitudinal axis and the boring tool. Operation is at the rate of 60 pistons per hour, the tolerance being — 0 to + 0.002 inch.

The next operation consists in boring the wrist-pin holes on a Warner & Swasey No. 4 turret lathe. The pistons are held in a box fixture, the axis of the wrist-pin holes being on the center line of the turret. The first tool coming into operation is a bar with 45 degree beveled end; this fits into the hole and ensures proper setting. The next turret tool is an ordinary drill, which straightens the hole. The next tool is a special three-flute piloted drill, the pilot entering the back of the box fixture; this drill sizes the hole within 0.010 inch of finished size, and final sizing is done by the last tool in the turret, which is a finishing reamer with left-hand spiral. The wrist-pin holes are left 0.004 inch small and reamed to exact size with an expansion hand reamer at the time of fitting. Production on the turret operation is about 50 pistons per hour.

The bottom of the piston is now squared with reference to the wrist-pin hole by setting the faced skirt on a surface

plate, and testing with an indicating gage, an accurately ground 10-inch bar being inserted through the wrist-pin holes. Tolerance of 0.002 inch is permitted.

A Cleveland automatic lathe is used for rough turning, facing, and cutting ring gains, the piston being centered by means of a cylindrical ring fitting into the skirt and held in position by a draw bar. The tooling is as follows: The front tool block carries the outside-diameter turning tool, while the back block carries the grooving tools, the ring grooves being finished in one operation. The head facing tool is carried on an independent cam, and the three operations are timed so as to finish simultaneously. The tolerance allowed on the width of ring grooves is ± 0.0005 inch and on depth is ± 0.003 inch. The outside diameter of the piston is turned only as preliminary to grinding. The capacity of this machine is about 60 pistons per hour.

The relief holes and smoke holes are drilled on a Sipp high-speed drill; a special fixture holding the pistons at an angle of 45 degrees being used for the smoke holes; no fixture is required for the relief holes. These are both rapid operations. The lock-pin boss is drilled on a jig; location is made by the skirt of the piston, and the piston is held in place by a pin through the wrist-pin holes. Oil holes are drilled in the wrist-pin boss without using a fixture.

The next three operations are spot-facing the lock-pin boss, tapping lock-pin boss, and cutting lock-pin grooves; these operations are carried out on a drill press using special tools.

Straight slots are cut by means of a 4-inch saw mounted on the arbor of a standard hand mill. Spiral slots are cut on a special fixture, using a saw, the piston being fed against the saw in such a way as to produce a spiral slit.

After the wrist-pin bosses have been milled on a hand miller carrying a ¾ inch end mill mounted directly in the arbor, the piston is rough and finish ground on a Norton grinder. On the rough operation, 0.020 in. is removed, while about 0.005 inch is taken off on the finishing grind. Tolerance on this operation is ± 0.0005 inch. The wheel used is Norton 36-L or Carborundum 303-NOD, lubricated by Houghton's Vitsol.

The piston is now inspected for outside diameter, proper clearance of the lands, depth and width of ring grooves, and quality of finish on all machined surfaces. Tolerance of — 0 to + 0.001 inch is allowed on the roundness. The total amount of machining scrap as borings is 6-7 ounces of metal, depending upon the size of the pistons.

Resumé of Experimental Work on the Production of Pistons

As mentioned previously, experiments were made by the writers on the production of aluminum-alloy pistons in permanent molds with the object in view of studying methods of gating and the causes for defects in the castings. The experiments were made under the operating conditions of practice in the plant of the Kant-Skore Piston Co., Cincinnati, Ohio, and while these experiments can not be discussed in detail in the present paper, the method of investigation and the main conclusions drawn will be taken up. Some special tests were also made of the ordinary shop practice during the course of the work.

As has been pointed out previously, the most usual defects occurring in permanent-mold-cast pistons are blowholes, air holes, overlaps, draws, cracks, and inclusions. Holes due to various causes are the most common defects encountered. Unlike a pressure die casting, permanent-mold-cast aluminum alloys are not normally porous, but they have a tendency to contain fairly large isolated holes; thus there may be only one or two holes ⅛-¼ inch in diameter in a piston casting. Such holes may be entirely internal and may or may not be revealed on machining, or they may occur at such positions on a casting as to be detected on hot inspection. However, in most cases, the presence of such holes causes rejection of the casting. One phase of the investigation reported briefly here consisted in examining the effect of different gating methods upon the occurrence of holes, and in other phases the effects of pouring temperatures and mold temperatures were studied. During the course of the work, some 1,000 piston castings were made, and record kept of the good and defective castings. All pistons cast were given a rough inspection when removed hot from the

molds, and, later, selected piston castings from each set of experiments were machined and then again examined for defects.

The confines of space do not permit publication of the large number of data obtained, but the complete results of the experimental work will be discussed in a later paper. During the time when the tests were made at the plant of the piston manufacturer, the average casting loss was at least 35 per cent, and for certain types of pistons mounted as high as 70 per cent at times. The loss due to machine shop returns was 10 per cent on the average for a casting loss of 25 per cent at the molds.

Alloy Used in the Tests:—The alloy employed for the tests had the composition,

Copper	9.50 per cent
Iron	0.71 per cent
Silicon	0.57 per cent
Nickel	0.56 per cent
Magnesium	trace
Aluminum (by difference)...	88.66 per cent

At the outset, 1 ton of alloy was made up and poured into pigs for remelting; this alloy was used exclusively in the experiments.

Melting Practice:—The alloy for the tests was melted in a tilting iron-pot furnace, oil-fired, and transferred while liquid to holding pots of 150-pounds capacity; these pots were simply stationary-crucible furnaces. The melting temperature was kept under 800 degrees Cent., and the holding pot was heated to about 750-800 degrees Cent. before the liquid alloy was transferred thereto. The alloy was well fluxed in the holding pot with zinc chloride and well skimmed before pouring; small addition of magnesium was made to the liquid alloy in the holding pot before pouring.

Pouring Practice:—The liquid alloy was poured into the molds with small iron dippers, as described in previous pages when discussing the general aspects of piston-mold operation.

During the course of the experimental tests, some temperature measurements were taken of the liquid alloy in holding pots used for production. In production, liquid alloy for pouring

may be dipped from the same holding pot by several molders, and it was of interest to find out the temperature drop in a pot while being emptied. Table 2 gives data showing the temperature changes in a pot of alloy when one, two, and three molders were casting therefrom. The burners were shut off, but the pot had been preheated prior to filling. In the first two cases there was an initial gain in temperature—due to heat absorption from the preheated pot. Cooling of the liquid alloy in the holding pot is hastened by the immersion of the dipping

Table 2

Temperature drop in holding pots during pouring runs.

Time, A. M.	Temperature of alloy in pot, degrees C.	Temperature drop, degrees C.
One molder casting pistons.		
9:38	776	..
9:48	780	+4
9:58	763	17
10:08	743	20
10:15	717	26
Total loss		59
Two molders casting pistons.		
10:30	780	..
10:40	790	+10
10:50	768	22
11:00	744	24
11:07	688	56
Total loss		92
Three molders casting pistons.		
11:20	780	..
11:30	775	5
11:40	750	25
11:45	705	45
Total loss		75

ladles. The data indicate the necessity for more accurate temperature control of holding pots.

Mold Employed:—The type of mold employed was similar in general construction to that shown in the drawings of Figs. 8 and 9 and the photographs of Figs. 10 and 11. Standard molds of this type were made up for casting 4-inch diameter pistons for a standard motor-car engine, and various methods of gating were tried.

Tests With Methods of Gating:—A number of different methods of gating were tried for the purpose of examining the effect of this factor on the quality of the castings produced and more particularly the occurrence of holes. It may be very prop-

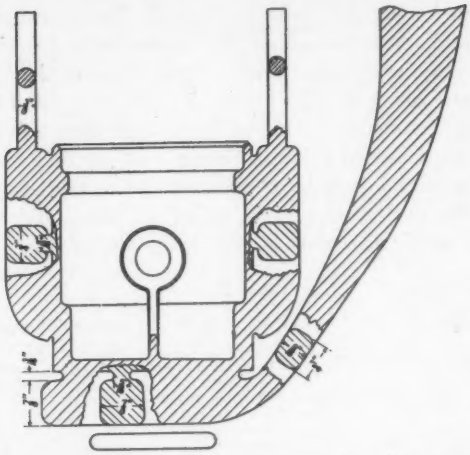

FIG. 22—GATING METHOD NO. 1; BOTTOM-FEED TYPE, WITH TWO LARGE SHRINK PADS, TWO THIN RISERS AND STRAIGHT FEEDERS (CF. CASTING IN FIG. 27)

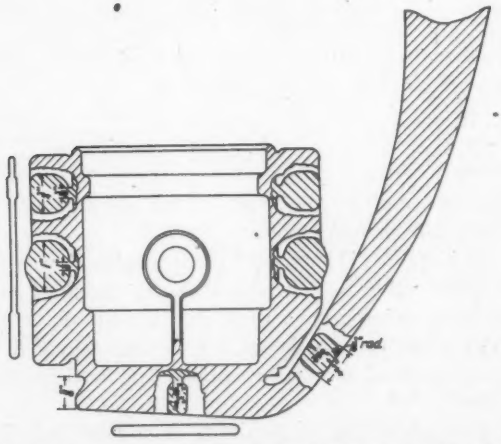

FIG. 23—GATING METHOD NO. 2; BOTTOM-FEED TYPE, WITH GRADUATED FEEDERS AND ENLARGEMENTS ON SHRINK PADS (CF. CASTING IN FIG. 28)

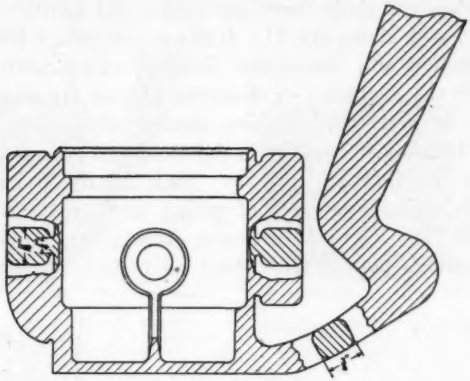

FIG. 24—GATING METHOD NO. 3; BOTTOM-FEED TYPE, WITH SHRINK PADS, AND TRAP POURING GATE (CF. CASTING IN FIG. 29)

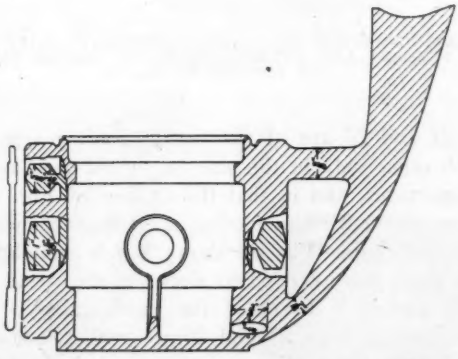

FIG. 25—GATING METHOD NO. 4; STANDARD BOTTOM-SIDE FEED GATE, WITH OVERSHOT, AND ENLARGEMENTS ON SHRINK PADS; GRADUATED FEEDERS (CF. CASTING IN FIG. 30)

erly emphasized again here that holes and cavities in permanent-mold-cast alloys are (1) draws or shrinkage holes, caused by contraction and inadequate feeding; (2) actual blowholes, caused by the evolution of dissolved gas on freezing; and (3) air holes or overlapped cavities, caused by entrapped air gathered by the alloy in its flow in the mold and accentuated by uneven flow in different sections. Figs. 22 to 26 inclusive are sketches showing five types of gating used in the experimental tests, and Figs. 27 to 31 inclusive show photographs of actual piston castings poured with these methods. The gates shown

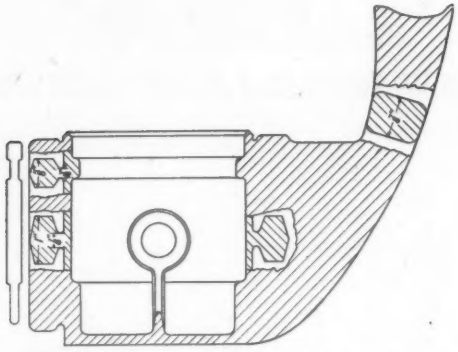

FIG. 26—GATING METHOD NO. 5; CROSS-FEED GATE, WITH GRADUATED FEEDERS AND ENLARGEMENTS ON SHRINK PADS (CF. CASTING IN FIG. 31)

in Figs. 22 and 23 are of the bottom-feeding type and differ from each other only in the size of shrink pads and shape of feeding apertures, and in that the casting of Fig. 22 has two thin risers attached. The feeding aperture is shown in outline in all the drawings. Fig. 24 shows a gate containing a trap; trap-type gates are intended to decrease the speed of flow of alloy and permit it to enter the mold quietly. The gating methods shown in Figs. 25 and 26 are similar, but differ essentially in the type of feeding aperture or choke and in the main feeding arrangement; in Fig. 25, an overshot is supplied so that the top will be fed, while in Fig. 26 the casting is fed along

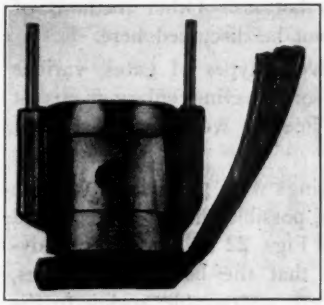

FIG. 27—PISTON CASTING WITH GATES ATTACHED; POURED WITH GATING METHOD NO. 1 (CF. FIG. 22)

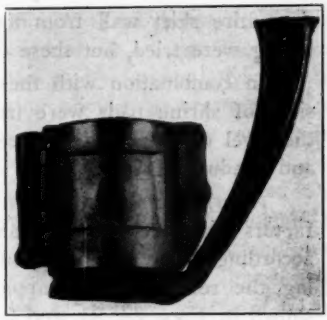

FIG. 28—PISTON CASTING WITH GATES ATTACHED; POURED WITH GATING METHOD NO. 2 (CF. FIG. 23)

FIG. 29—PISTON CASTING WITH GATES ATTACHED; POURED WITH GATING METHOD NO. 3 (CF. FIG. 24)

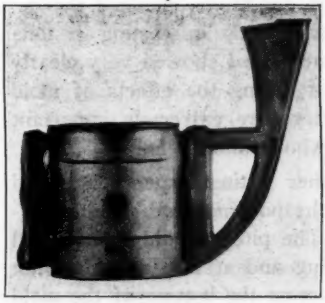

FIG. 30—PISTON CASTING WITH GATES ATTACHED; POURED WITH GATING METHOD NO. 4 (CF. FIG. 25)

FIG. 31—PISTON CASTING WITH GATES ATTACHED; POURED WITH GATING METHOD NO. 5 (CF. FIG. 26)

the entire skirt wall from top to bottom. Other methods of gating were tried, but these can not be discussed here.

In combination with these several types of gates, various sizes of shrink pads were used, some having enlargements at the level of the wrist-pin boss. Feeders were of the straight and graduated types.

A large number of piston castings were poured, all variable factors being kept as constant as possible, using molds gated according to the methods shown in Figs. 22 to 26. After studying the results, it was apparent that the bottom-feed gates, shown in Figs. 22, 23, and 24, were undesirable, owing to the disturbance of the liquid alloy in the bottom of the mold. With this type of gate, the liquid alloy first entering the mold becomes chilled and sluggish and retards proper filling of the mold cavity. The trap gate shown in Fig. 24 had no especial effect on the occurrence of defects, as compared with the gates in Figs. 22 and 23, but the results did indicate that especial curves in the contour of the gate are not necessary. The best types of gates were those shown in Figs. 25 and 26, in which the liquid alloy first deposited in the bottom of the mold was least disturbed. The experimental castings poured, using these five types of gates, were made under production conditions, and, owing to these conditions, neither the mold temperature nor pouring temperatures could be held constant. The result was that during periods when the mold and pouring temperatures were correct, good sound pistons, substantially free from holes, could be produced, but when these conditions changed the defects again appeared. Preliminary work in casting pistons with the five methods of gating mentioned showed very clearly that irrespective of the method of gating the effects of mold temperature and pouring temperature are extremely important as related to the occurrence of blowholes and air holes.

The results of these and other gating experiments, and practical observations, show that the pouring gate should preferably be as simple as possible. The pitch should be adjusted as to angle so as to avoid splashing and at the same time not cause the liquid alloy to be shot across the bottom of the mold and up the opposite side. Preferably, the gate opening into

the mold cavity should be flat and wide as shown in Figs. 25 and 26, and it might be advantageous to arrange the opening so that the alloy would enter the cavity tangentially with the piston circumference. The gating should be arranged so as to avoid splashing and agitation of the liquid alloy on entering the mold cavity and on rising therein.

Flow of Liquid Alloy in Molds:—The rate and direction of the flow of alloy in a mold cavity are directly controllable by the type of gating, the arrangement of the feeders and their size and shape, and by the size and shape of the shrink pads. Overlaps and air holes in castings are directly traceable to uneven rise of alloy in the mold cavity, and it is essential to adopt

FIG. 32—OVERLAP IN WALL OF PISTON CASTING

a method of gating and arrangement of feeders that will ensure even flow of the alloy. It would be interesting and useful to make experiments on the flow of bright-colored liquid wax in transparent molds so that the actual flow could be observed in process. Time was not available for developing an experimental method in this direction, and the alternative was adopted by the writers of pouring molds partly full of alloy in successive steps, i. e., increasing the amount of pour from about 1 inch depth in the mold cavity to a fully poured mold. This method of pouring short castings is very useful for determining the course of travel followed by the liquid alloy in its flow in the mold, and gives data as to the weak or slow-filling parts of the cavity. Short castings were poured using the several types of

gating, and it was found that the heavy sections nearly always ran more rapidly than the light sections. In some molds, owing to uneven flow, very good examples of the effect of uneven flow on the formation of holes were observed. Thus, in certain cases, the liquid alloy filled the rib cavities before the thin portion of the wall, then arched over or overlapped, and formed a pocket of entrapped air. Fig. 32 shows a hole formed in this manner in a piston casting. The hole extends through the piston wall.

Under various conditions of pouring, air pockets of the type described assume various forms; sometimes they result in holes which run entirely through the piston wall, while in other cases, e.g., if the alloy is poured very rapidly, entrapped air bubbles are broken up and result in small holes that are not revealed until the piston is machined.

Fig. 33 shows a set of piston castings poured short, using gating method No. 3 (cf. Fig. 24); the uneven flow of the liquid alloy, resulting from particular conditions of the mold and operation, is shown (cf. also Fig. 16). The effect of mold temperature, and variation in mold temperature, on the flow of liquid alloy in molds has been previously discussed (cf. Fig. 17), it being pointed out that the flow is increased with increasing mold temperature.

Overlaps and entrapped air holes can be eliminated largely by control of the flow of alloy in the mold, and in practice it is advisable to alter the size and shape of the feeders and shrink pads so as to direct liquid alloy to the weak and slow filling portions of the mold and thus equalize the flow in all parts. Fig. 34 shows a set of short pistons, poured with gating method No. 1, using small shrink pads, and Fig. 35 shows another set poured with the same gating method but after enlarging the shrink pads. Heavy shrink pads, although unnecessary for feeding purposes, are undoubtedly of value in regulating the flow of liquid alloy. Increasing the pouring temperature is of assistance in filling thin sections, but a high pouring temperature induces cracking and increases the contraction.

The rate of flow in sections of different size, as affected by gating, mold temperature, and pouring temperature, may be studied very conveniently by pouring a casting such as shown

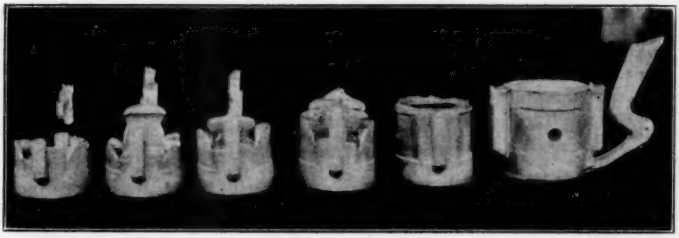

FIG. 33—PARTLY FILLED PISTON CASTINGS SHOWING UNEVEN FLOW OF ALLOY; POURED UNDER OPERATING CONDITIONS (CF. FIG. 16)

FIG. 34—PARTLY FILLED PISTON CASTINGS, SHOWING UNEVEN FLOW OF ALLOY; SMALL SHRINK PADS

FIG. 35—PARTLY FILLED PISTON CASTINGS, SHOWING MORE EVEN FLOW OF ALLOY THAN IN FIG. 34; LARGER SHRINK PADS

in Fig. 36. The mold is made of two halves and holes of various sizes are drilled; the casting is poured and the rise of alloy noted. Various molds of this type can be made in which the method of gating can be altered as well as the distance traversed by the alloy in flowing to fill thick and thin sections. A large number of castings of this type were poured in the investigation in which the effect of mold temperatures and pouring temperatures were studied.

Effect of Feeders:—Experiments were made with different types of gating in which the size and shape of the feeders or

choke openings were altered. As explained previously, straight and graduated feeders were tried, and the experiments showed that the choke opening should be graduated and flared so as to spread the alloy evenly and also adjusted as to size, depending upon the size of piston cast—larger pistons require larger openings.

Effect of Shrink Pads:—Experiments were made with several types of gating in which the size and shape of the shrink pads were altered. It is felt by the writers that the shrink pad opposite the pouring gate is not always necessary, and that in

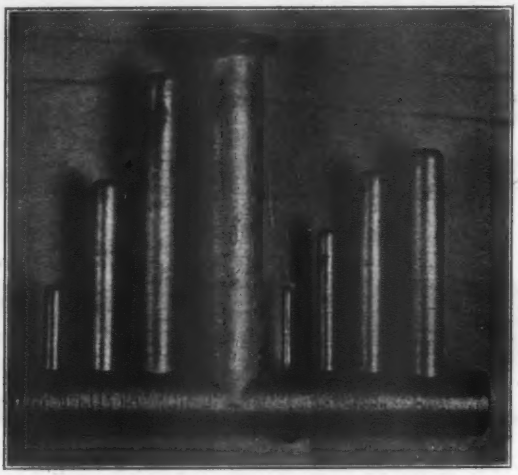

FIG. 36—CASTING WITH THICK AND THIN SECTIONS SHOWING VARIATION IN RISE OF LIQUID ALLOY

some cases this can be eliminated, thereby reducing the amount of gating scrap. Large shrink pads are useful in regulating the flow of alloy, however, as has been pointed out above.

Effect of Pouring Temperatures:—Experiments were made using several methods of gating and varying the pouring temperature in the range 650 to 820 degrees Cent., all other variables being kept as constant as possible. Temperatures were taken with a Wilson-Maeulen pyod. In general, it is safer to

pour aluminum alloys at higher temperatures in permanent molds than in sand molds, from the point of view of mechanical properties and microstructure as well as soundness. As previously explained, a higher pouring temperature causes more even flow of alloy and ensures better filling irrespective of the gating or the size and shape of shrink pads and feeders. At the same time, a higher pouring temperature increases the cracking tendency and also the amount of contraction and consequently the occurrence of draws.

The writers feel that definite pouring temperatures for particular molds can be arrived at best by trial—different molds yield the best results for particular pouring temperatures, other conditions being the same. In general, however, it is advisable to pour at as low a temperature as is consistent with the alloy filling the mold well and avoiding cold shuts. More dense pistons are secured by lower pouring temperatures, and this is desirable. For the type of piston casting made in the present experiments and with the methods of gating used, it was found that when the alloy was poured at temperature higher than 760 degrees Cent., the cracking and drawing tendency increased. Pouring at 800 degrees Cent. tended to eliminate uneven filling and overlaps, but these difficulties can be corrected by increasing the mold temperature and by altering the gating. The best pouring temperature for the molds used varied with the individual molds, but the most suitable pouring temperature for aluminum-alloy pistons lies in the range 725 degrees to 775 degrees Cent.

Emphasis has been laid upon the necessity for accurate control of pouring temperatures, and the writers recommend continuous pouring from a holding pot in which the temperature is controlled within close limits.

Effect of Mold Temperatures:—As pointed out, the temperature of the mold and cores is extremely important as affecting the occurrence of certain defects, the quality of the castings, and the rate of production. A series of experiments was carried out using gating methods Nos. 4 and 5 (cf. Figs. 25 and 26) in which pistons were cast using mold temperatures in the range 300 to 540 degrees Cent. It was found

that the best all-around results were secured by operating at 300 to 400 degrees Cent.; the cores should be somewhat cooler than the mold proper. If the upper temperature, 400 degrees Cent. is exceeded, the casting freezes and cools too slowly, and production is decreased because the part must remain longer in the mold before it can be removed for fear of breaking; moreover, the favorable effect of chilling on the mechanical properties is partly lost. If the temperature falls below the lower limit, 300 degrees Cent., the casting may run cold shut, unless the alloy is poured at excessively high temperature.

The actual operating temperature of a piston mold varies considerably in practice, i.e., among different similar molds, and the temperature also varies among different parts of individual molds. When a previously heated mold is put into operation, there is normally considerable variation in temperature throughout the mold mass, and more particularly between the top and bottom of the mold. With successive casts, the temperature throughout the mold tends to become uniform, but this may not always follow in practical operation since there are a number of interfering factors that cause fluctuations in mold temperatures; viz., interrupted pouring, quenching of cores, and uneven heat radiation due to the design of the mold, as well as variation in time period during which the casting remains in the mold prior to removal. The prime requisite in the matter of mold temperature, other than that the mold shall be at the proper temperature, is uniformity of temperature throughout the mass. Much of the difficulty obtaining in control of mold temperature is due to poor design of burners for heating. Burners should be arranged to heat the entire side walls instead of projecting flames locally, and electric-resistance heating would be ideal. The thermal properties of ordinary molds as to heat losses could be improved by designing the molds so that the mold cavity is centrally situated in the closed blocks, with respect to the distance from the walls in all directions. The mold walls should preferably be of uniform thickness, and molds might very advantageously be insulated so as to give uniform heat losses and also to prevent excessive loss of heat. Uniform distribution of heat in a mold tends to give uniform flow of alloy on pouring.

Ordinary molds of the type under discussion normally operate with the bottom colder than the top, and the variation found on measurement was from 15 to 110 degrees Cent. Mold temperatures taken on a number of different molds in production showed that the temperature varied considerably in different molds and in different parts of the same mold. It may be advantageous to run the bottom of the mold at lower temperature than the top when casting pistons in the inverted position so as to provide for more rapid cooling of the heavy head, but it is the writers' opinion that the mold is best operated with a uniform temperature throughout. In practice, with ordinary molds, it is rarely necessary to cool the blocks when using the interrupted pouring system, and when necessary external heat can be supplied by lighting the burners. When the continuous pouring system is used, the mold temperature may run too high after a number of casts, and the mold walls can be cooled by an air blast or by splashing with water. It is advisable, however, to design the molds of such size and mass that they can be operated at 300-400 degrees Cent. with continuous pouring. Cores are ordinarily cooled by momentary dipping in water.

The time period during which the piston casting is allowed to remain in the mold after pouring depends upon conditions; ordinarily, the casting cools in the mold for 10 to 40 seconds, depending upon the size of piston, the mold temperature, and the pouring temperature. In practice, castings are removed from molds as soon as the cores can be lifted and the mold halves parted without breaking the hot casting. Normally, castings should be removed as soon as possible so as to prevent cracking by contraction around the cores.

Mention has been made previously of the effect of uneven heating and variation in mold temperature in different sections of the mold upon the flow of alloy. Some experiments were made in which the burner on one side of the mold was turned on while the other was left off so that one side of the mold would be much hotter than the other, and a number of castings were poured. Under such a condition, it is almost impossible to produce good castings because of overlapping of the alloy

and the resultant entrapping of air. These experiments were interesting in showing the effect of variation of temperature in different parts of the mold upon the flow of alloy. Of course, the condition set up is exaggerated over that actually obtaining in a normally operating mold. The effect of such variation in wall temperature in the two halves of a mold is shown very nicely by Fig. 17; the high sides of the partly filled pistons were against the wall of higher temperature.

Casting Experiments With Two Molds:—Experiments were next made using two molds gated as shown in Figs. 25 and 26. On the basis of previous tests, the operating temperature of the mold and the pouring temperature were selected to give the best results, and the size of shrink pads and choke openings were adjusted until the flow of alloy was satisfactory. A large number of piston castings were then made. The results were very satisfactory, and it was shown that wasters can be very markedly reduced by accurate control of the several variables. The writers feel that the average casting loss should not exceed 5-7.5 per cent under proper conditions.

Summary and Conclusions

In this paper the production of aluminum-alloy pistons has been discussed in some detail, and the operating details of the permanent-mold process as applied to piston casting have been described. Various types of piston molds have been discussed, and the effects of the most important variables on the production of sound castings free from defects have been considered. The design of molds on the basis of a consideration of the desired flow of liquid alloy on pouring has been taken up, and the general principles of satisfactory design have been elucidated. The question of mold operation has been discussed as well as the employment of various kinds of aluminum alloys. In considering the problem of defects in piston castings and wasters in production, the relation of machining has been pointed out, and typical machine operations have been described. The effect of heat treatment, i.e., simple annealing, in overcoming growth and distortion of pistons is discussed briefly. A resumé has been given of an investigation on methods for gating

pistons and on the effects of mold temperatures and pouring temperatures upon the occurrence of air holes, overlaps, cracks, and related defects.

On the basis of the experimental work, the following conclusions are drawn:

1. Piston molds should be designed of such size and mass that they can be operated at the proper temperature with continuous pouring.

2. Simple types of pouring and feeding gates are preferable, and cross-feed or side-feed gates were found best of a number tried. Bottom-feed gates did not give good results.

3. Graduated feeders, arranged so as to spread the liquid alloy out as it enters the mold, and of proper size for the thickness of section fed, are better than straight feeders.

4. Shrink pads should be provided at suitable positions on the casting, and usually at a heavy section corresponding to the gate feed. Shrink pads, in addition to feeding the casting, are useful in controlling the rate of flow of the alloy.

5. The rate and uniformity of flow of liquid alloy in a mold cavity is very markedly affected by the design of the pouring gate proper (i. e., as to its size and pitch), by the form of choke, by the size, shape, and location of shrink pads, by variation of temperature in different parts of the mold as well as by the average mold temperature, by the size of the cavity sections, and by the pouring temperature. Control of flow may be had by control of these several variables.

6. Air holes, overlaps, and related defects in castings are very markedly affected as to occurrence by rate of flow, and consequently by the factors affecting rate of flow.

7. Cracks and draws are caused by too high pouring temperature.

8. The pouring temperature should preferably be as low as is consistent with the alloy properly filling the mold, and pouring in the range 725 to 775 degrees Cent. is suitable for most types of pistons.

9. A holding pot should be provided in which nearly constant temperature of the alloy can be maintained; an electrically-heated pot would be desirable if not too expensive.

10. Mold-heating burners should be designed and arranged so that the mold walls are heated uniformly over the surfaces and not locally in small spots.

11. The mold temperature should be 300-400 degrees Cent., depending upon conditions, and it is essential that the temperature be uniform throughout all parts of the mold.

12. Suitable thermal conditions in a mold can be secured by proper design, proper heating arrangements, and insulation if required.

13. The alloy used should have good casting qualities, and the best alloy from this point of view is the one having the least contraction.

14. In order to minimize the friction of the moving liquid alloy against the mold surfaces and thereby obtain uniform flow of alloy as well as smooth castings, it is desirable to polish the cores and inside of the mold cavity.

15. Whereas the average casting loss incurred in piston production may be about 35 per cent under conditions where poor control of the various factors influencing the occurrence of defects obtains, this can be reduced to 5 per cent under proper conditions.

16. Accurate casting loss record, together with record of mold and pouring temperatures, is invaluable in determining the causes for wasters.

Selected Bibliography

The following references include the papers cited in the text as well as some others; the principal papers relating to permanent-mold casting of aluminum alloys are given as well as some dealing with the properties of aluminum alloys, the use of aluminum-alloy pistons, and the machining of pistons.

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Discussion—Production of Aluminum Alloy Pistons in Permanent Molds

S. DANIELS: I would like to ask what alloy this is.

J. B. CHAFFEE: About 8 per cent copper and 2 per cent silicon.

S. DANIELS: Are you casting anything in the line of the regular piston alloy?

J. B. CHAFFEE: We are casting some stuff somewhat like the piston alloy. We use an alloy that has the high Brinnell of the piston alloy.

S. DANIELS: Are you heat treating any of your castings?

J. B. CHAFFEE: No.

S. DANIELS: The reason I ask this is that we have found that we can take the piston alloy and approximately double its ultimate strength by using heat treatment. In my alloy I develop an ultimate strength of as high as 48,000 pounds per square inch.

J. B. CHAFFEE: I regret to say that I cannot tell you anything about that particular line because our customers have not asked for heat treated castings as yet. I think unquestionably you are going to have manufacturers wanting 35,000 to 40,000 pounds per square inch tensile strength in aluminum castings, but up to now we seldom get inquiries for anything of that sort, and therefore have not gone into it.

V. REED: At what temperature would you pour castings like this? How do you handle a core of this kind? Do you have trouble from cracking with a steel core in the center? How do you handle that core in the mold?

J. B. CHAFFEE: We poured that as low as we possibly could pour it, about thirteen fifty. You pull the core practically as soon as your metal is frozen, almost immediately.

N. K. B. PATCH: I do not think the permanent mold is appreciated as much as it used to be by the average foundryman, outside the automobile industry. The permanent mold process opens up a field of operation that has been very hard to cover in the past. We have now in the molding game three different forms of castings—sand castings, pressure die castings and permanent mold castings—and each one of them has a very definite field of operation. The pressure die castings, with the metal molds being chilled on the outside and the

metal forced in under considerable pressure, lends itself particularly to operations where we have very large production and where sharpness of outline and the elimination of any machining process is particularly important, but due to the process employed in pressure die castings, the metal is being forced in under high pressure and therefore the gates through which the metal flows must be kept relatively small. As a result, the gate is generally the first place where the metal freezes. Then inside of the mold the metal lying against the chill freezes first. Since the path to the base is shut off due to the freezing of the gate, the outside of the metal of the casting must draw from the inside, and therefore, while the pressure die castings have a very fine outline, exceedingly fine outline, it is practically impossible to find any pressure die casting which does not show a porous structure full of blowholes if you cut it apart. A pressure die casting is therefore really unsuitable where any definite requirements as to physical strength, etc., must be met. Furthermore, on account of the fact that the outside of the mold is chilled, is artificially cooled, the stresses in the die itself are quite considerable. The mold must be made of very expensive material and it must be dimensioned so as to stand these enormous stresses, and the dies for pressure die castings are of necessity very expensive.

Now in the permanent mold process you employ practically the opposite method. You do not use any pressure to force the metal in except the hydrostatic pressure due to the head of the casting, and therefore you can make your gate as large as you want to; you can make your base as large as you want to. The outside of the mold as a rule is not cooled; sometimes it is cooled mildly, but generally the outside of the mold is allowed to attain a rather high temperature. As a result, you get a less violent chilling of the metal; you preserve the base, and the casting if made in the proper way is 100 per cent perfect. You get not only the advantage of the finer structure due to the chilling of the casting, but you are able to take advantage of that finer structure throughout the whole casting. I remember when Mr. Chaffee, some time ago, had some balls about two and three inches in diameter cut apart. The balls were made in chilled castings; they were cut apart, and the Brinnell from the outside of the casting down to practically the inside of the casting did not vary more than about 10 per cent, indicating a very uniform structure. Now what I want to lead up to is that permanent mold castings allow us, for mechanical purposes, to make castings which get us away from the great difficulty of sand and pressure die castings; that is, they are uniform in their performance and they bring out the best that is in the metal, and they allow us to use aluminum in the mechanical industry where in the past, due to the unreliable features of the aluminum sand castings, etc., we simply could not do it. That is all I wanted to bring out.

MR. JACKSON: In regard to the statement of a previous speaker, I want to favor sand cast units as a production proposition, but in regard to the uniformity of pistons, we found that in the chilled cast piston itself there may be some uniformity of volume, but as between pistons A, B and C you do not find that uniformity of Brinnell hardness in the sand cast pistons which we have been making, and also the Y alloy, that is to say, the 4 copper, 2 nickel and 1½ magnesia. In sand we have been getting very uniform results. We cast them with a red brass chill against the crown, and after heat treatment (we heat treat all our pistons) we have been getting remarkably uniform results, and in the skirt we get a uniform Brinnell hardness of about 90 and in the crown we get a Brinnell hardness of as high as 120. I think that is very interesting indeed to those who are particularly interested in pistons.

One of the desired factors on the piston is high Brinnell hardness; that is, some manufacturers say it is and others say it is not. I know of one manufacturer that wants his pistons up to 140 or 150 Brinnell, which is quite hard, harder than bell metal bronze. Other manufacturers are quite well satisfied if they have their pistons down to 90 Brinnell, and object strenuously if it goes up to 115 Brinnell. Really, the automobile manufacturers do not know what they want yet in aluminum pistons.

S. DANIELS: In the aircraft engine game we come in contact with some interesting things. One piston in the Y alloy accidentally happened to get into the engine without heat treatment and was sent back to us in a finished machined condition, and we heat treated it, which consists of heating to 950 Fahr. and boiling in water for 16 hours, and we put that piston back into the engine with no distortion of measurement.

J. B. CHAFFEE: That is a very interesting thing. I know that during the war the British claimed that they had considerable trouble from distortion of the aluminum castings which had not been heat treated, and today many of the manufacturers will tell you that the reason that they heat treat their aluminum pistons is to take out this small tendency toward distortion. They may distort and they may not, but the tendency today seems to be to heat treat all aluminum pistons to prevent distortion if nothing else. I do not want to speak for any of the companies making aluminum pistons. We do not make them, but that is the tendency today largely to anneal rather than heat treat, but there no doubt will be a tendency to heat treat; if the customers desire the higher Brinnell, they must get that by heat treating.

CHAIRMAN W. M. CORSE: I happen to have seen the Holly process in Detroit, and they seem to be doing very well with cast iron in metal molds and are getting many of the results described in aluminum. It seemed to me that there is quite a possibility for other metals than

aluminum in that type of mold, as they make pistons, and their cast iron castings in the shape of a piston are lighter than aluminum pistons.

J. B. CHAFFEE: That is the engineer's specifications. There is a new piston that has just been put in to replace aluminum pistons, but the whole piston design is a question of discussion among engineers, the engineers do not know what they need as aluminum pistons today, which is pretty well borne out by the fact that if you pull an aluminum piston out of one kind of a car and compare it with an aluminum piston that you pull out of another car, they are entirely different. If we should go into a discussion of aluminum pistons, we would get into a real hot discussion.

CHAIRMAN W. M. CORSE: For the type of piston they wanted, the sand casting was not satisfactory but the permanent mold was satisfactory, so that it apparently gives the man who is making that type of thing a new tool that he did not have before. And in this process in Detroit they are using a coating on their mold which is part of their patent, I believe, and there seemed to be a tendency toward this same progressive cooling that you described as being ideal, and it seems to be one more thing to help them with slow cooling. Fast cooling and a heavy chill is not satisfactory, you have to design your mold so that it will cool progressively. If you succeed in doing that ideally, don't you reduce your total shrinkage?

J. B. CHAFFEE: Yes, by the fact that you are using .1 instead of .15 or .125 for aluminum alloy. .125 is your silicon alloy, but .156 is your ordinary pattern shrinkage.

CHAIRMAN W. M. CORSE: But that depends on the design of the mold?

J. B. CHAFFEE: Yes, you have no crystallization in shrinkage in a well designed permanent mold casting; all you have is true thermal shrinkage.

CHAIRMAN W. M. CORSE: What do you mean by crystallization in shrinkage?

J. B. CHAFFEE: It is the difference in the volume of the metal when it is liquid and when the same amount is cold and solid. That varies all the way from about 3½ per cent, or 13 per cent with silicon alloys, up to about 6 or 8 per cent on copper aluminum alloys high in pure metal.

CHAIRMAN W. M. CORSE: And to that you have to add your thermal shrinkage due to the drop in temperature from the time it starts to solidifying until it is finally cooled to room temperature?

J. B. CHAFFEE: Yes, and then you have a correction factor because your mold has expanded from its normal temperature to sand temperature.

CHAIRMAN W. M. CORSE: In a sand casting you get shrinkage?

J. B. CHAFFEE: To some extent, but if it is well designed you

feed it straight from the gates and risers so that you do not have as much shrinkage.

CHAIRMAN W. M. CORSE: I have seen it stated that the pattern maker's shrinkage is less in a permanent mold than in a sand mold. Therefore you get results with Monel metal or nickel alloy which uoght to be desirable due to lower shrinkage?

J. B. CHAFFEE: You have a lot of trouble with them, but it is desirable.

D. BASCH: In connection with that I want to bring out a point that ought to be brought out, that the shrinkage in a permanent mold casting is really greater, and that is very easy to be understood, because if you take a permanent mold casting, it is much more dense than a sand casting and it weighs more. Mr. Anderson in one of his previous papers brought out the point that just quantitatively the shrinkage in the permanent mold casting is apt to be greater than in a sand casting.

J. B. CHAFFEE: We do not find it that way from a lineal dimension standpoint, but we do find very definitely that if you take the same alloy and cast it in a permanent mold casting and the same in sand, even from the same heat, and if you take the specific density of the metals, you will find that the permanent mold casting gives 3 to 5 per cent greater weight per cubic inch than the sand casting.

CHAIRMAN W. M. CORSE: That is what you mean by saying that it takes more metal to make it?

D. BASCH: You fill the same cubical contents of the mold, you pour the same amount of hot metal in there; now then the casting you get out has a greater density; where does the difference go? It naturally indicates that there is a greater shrinkage, right on the face of it, and Anderson brought actual proof on that point.

CHAIRMAN W. M. CORSE: The unfortunate point in all this discussion is that the word shrinkage is used to designate two or three different things; that is where the trouble comes.

D. BASCH: I mean the total shrinkage, which is made up of the liquid contraction, the solid contraction and the crystallization shrinkage.

CHAIRMAN W. M. CORSE: Then you have the pattern maker's shrinkage, which refers to dimensions.

D. BASCH: That is right; we are very loose in our use of terms.

R. R. KENNEDY: Could you give us the number of castings necessary before you get economical production? Say you have a production of a couple of hundred castings per day; would it pay?

J. B. CHAFFEE: We have done work for certain companies wherein they desired a very high grade casting and the total quantity was only 400 castings. That is all they wanted, was 400 castings; but they had to have a particularly high grade casting. Now molds cost

them $450 and the castings cost them about $2.25 apiece, yet they told me afterwards that they had saved on that job over $200 by placing that in the permanent mold compared with what they would have had to do if they had taken sand castings and done the machine work. You see in permanent mold castings in some cases you can hold relatively close dimensions, but we normally will state that our dimension tolerance is plus or minus a ten thousandth of an inch. For some work that is close enough, and for other work you have to machine. So in answering your question I would say that taken on the whole, a production of 50 a day warrants the use of a permanent mold casting. I know of many motor car manufacturers that are having castings made in permanent molds where they do not have a production of 20 a day, and those castings are in direct competition with sand.

MR. MCKNIGHT: In Table 1, there are given quite a few typical analyses of permanent mold castings. These are especially the piston alloys. I would like to ask what grade of ingot does the manufacturer of a permanent mold casting have to specify in order to get one that will work well? I notice, for instance, 1½ per cent of iron on quite a few of your castings; in fact, that is the specification here. Do you have to use a 99 to 100 per cent ingot? How much iron can you have in the original ingot? How much do you pick up during your process of melting? How much comes from the mold? How much do you have to figure to get 1½ out of it?

J. B. CHAFFEE: I do not like to answer that for this reason, we do not make pistons, therefore I would hate to say that the piston manufacturers used 99 plus metal or 98 metal. I do not want to say so because we are not in that business, but for our own castings, for permanent mold aluminum castings made by our own company, we use what is necessary to meet the customer's requirements. Normally we use 98-99 metal. There is 1½ per cent iron when we make a casting which is of the type of piston metal. We deliberately add iron, because we get a good hard boring metal by doing so. We are making valve tappet guides for motor cars, and it works out very well indeed in that hard alloy; we get a hardness of about 120 Brinnell, from 110 to 120, by using an alloy which is somewhat of the type of those alloys spoken of in here.

MR. MCKNIGHT: I would like to ask another question then; for instance, the 98-99 ingot as produced today, especially virgin 98-99, will run all the way from .4 to 1 per cent of iron. How much iron do you have to add? That is just another way of putting it. What I am especially anxious to know is how much do you pick up from your mold and in your melting?

J. B. CHAFFEE: We figure that we do not pick up any from the mold, and what we pick up from the melting is absolutely dependent on the way in which you keep your taps and is dependent on the alloy you are using. If you use a 5 per cent silicon alloy, you may pick up

1½ per cent iron in a single melting. It is largely a case of what your conditions are in your own foundry. In some instances we have started with a virgin metal having .6 per cent iron, normally a fair figure for iron, and in the finished casting you will have probably .8 to .85 per cent. That is, after melting it in an iron pot and pouring it into an iron mold. I do not think that the fact of your pouring it into an iron mold changes your analysis that much, because it does not stay there long enough.

S. DANIELS: In our pistons we are using 99 and 99.5 ingot and the iron sometimes there is as low as a quarter of 1 per cent, and as you say, we look for the iron in the form of aluminum copper iron, and I should say that in order to bring up the iron to 1.5 per cent, we usually add about half of that. And, by the way, that lynite, 122, also has a quarter per cent magnesium.

Aluminum Alloy Castings From Sheet Scrap

By Horace C. Knerr, Philadelphia, Pa.

The purpose of this paper is to outline the methods by which a very small foundry, started on an experimental basis, succeeded in meeting the requirements for sound and dependable aluminum alloy sand castings, only scrap aluminum sheet and copper available at the factory being used.

The paper is offered to the American Foundrymen's association with considerable hesitation, as the author may qualify as a foundryman only by force of circumstance, and not by training or experience. He therefore begs the tolerance of the members who are more expert in this field, and hopes that the report may be of some assistance to those who desire to undertake the production of aluminum alloy castings on a small scale, or who are experiencing difficulty in obtaining sound castings, or to whom the use of sheet scrap for this purpose may be a novelty.

The castings in question are required to meet government specifications corresponding approximately to the well known commercial alloy No. 12 or to S. A. E. Specification No. 30, as follows:

Composition

Copper—7.0 to 8.5 per cent.
Impurities—1.7 per cent max.
Aluminum—Remainder.

Physical Properties

Specific Gravity—Not over 2.89.
Tensile Strength (Min.)—18,000 lb. sq. in.
Elongation in 2 in. (Min.)—1.5 per cent.

These castings are used chiefly for small, moderately

stressed parts of aircraft and their accessories, such as pulleys, brackets, portions of the control mechanism, parts of fuel and oil pumps, threaded fittings and connections in gasoline tanks and lines, etc. A few examples are shown in Fig. 1. In fuel lines, non-porosity is essential, and the fittings are required to withstand an air pressure test of 10 pounds per square inch without leakage, and must be capable of welding to commercially pure (99 per cent) aluminum sheet and tubing. (Where high

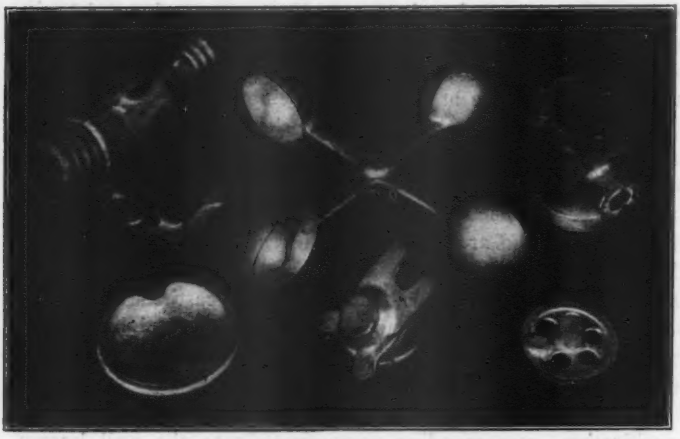

FIG. 1—EXAMPLES OF 8 PER CENT COPPER—92 PER CENT ALUMINUM CASTINGS USED IN AIRCRAFT. THE FITTINGS IN THE UPPER RIGHT AND LEFT HAND CORNERS MUST BE NON-POROUS.

strength and lightness are required, special heat treated commercial aluminum alloy castings are purchased.)

Much difficulty and annoyance were experienced in attempting to obtain castings from outside sources to meet these moderate requirements. A large proportion of the castings received were exceedingly porous, spongy and unreliable in strength. Many of them had inclusions of foreign matter which interfered with machining and caused weakness. Figures 2 and 3 show typical examples. Delay in delivery, high charges per pound in small lots, and the cost of the paper work incidental

FIG. 2—CASTING OF HUB OBTAINED FROM OUTSIDE SOURCE. NOTE EXTREME SPONGINESS.

to purchase, were further objectionable features. It was therefore decided to attempt to produce the required castings within the plant, although no foundry work had hitherto been done there.

First Experiments

The work was undertaken on an experimental basis. A small, second hand oil fired tilting brass furnace was obtained, flasks and a molder's bench constructed, and molders' tools and a ton of medium fine Albany sand were purchased.

Melting was at first done in graphite or plumbago crucibles but the results were unsatisfactory, presumably on account of

the access of furnace gases to the molten metal. A pot was therefore made of welded steel sheet and tubing, as illustrated in Figure 4, which completely excluded furnace gases from the metal. A pronounced improvement resulted, and this was in fact the first step in obtaining sound and satisfactory castings. Although intended for experimental use only, the original pot is still in service, at the time of writing, after more than 100 heats, having been repaired several times by welding.

Examination of the interior of the pot after months of use shows very little attack, and it is evident that little or no iron

FIG. 3—CASTING OF WINDVANE OBTAINED FROM OUTSIDE SOURCE. NOTE PEBBLE EMBEDDED IN FRACTURE.

has been taken up from it by the aluminum. No protective coating was used, inside or out. Repairs, or a new bottom, were necessary on account of failure of the welded seam, or by burning through from the outside where in contact with the flame. It is intended to replace this pot by a cast iron pot, to avoid welded seams.

Porous Scrap Castings Found Unsatisfactory for Remelting

It was at first attempted to produce the required castings by remelting scrap aluminum alloy crank cases and similar parts from aircraft engines. These castings were of practically the same composition as called for, but were for the most part very porous. They did not produce sound castings when remelted.

A quantity of 99 per cent aluminum pig was purchased, and the requisite amount of copper added in the form of chopped copper sheet, tubing and wire from the scrap bins. A high percentage of the resulting castings still had to be rejected for porosity.

A considerable quantity of 99 per cent aluminum sheet scrap was available in the plant from the manufacture of fuel

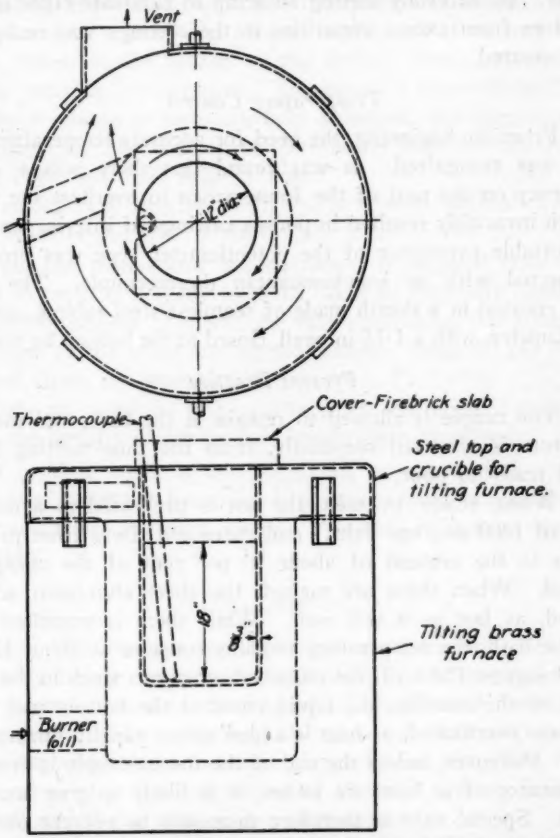

FIG. 4—OUTLINE SKETCH OF TILTING BRASS FURNACE ADAPTED FOR MELTING ALUMINUM WITH POT TO EXCLUDE FURNACE GASES FROM METAL.

tanks, cowling, and other parts for aircraft. Remelting this scrap, with the addition of scrap copper sheet and tubing gave the best results which had so far been obtained. The use of other materials was therefore discontinued, there being ample sheet scrap available to meet the needs of the foundry. The sheet and tubing from which the copper scrap was obtained was purchased under specifications calling for 99 per cent purity. By carefully sorting all scrap to eliminate other metals, freedom from excess impurities in the castings was reasonably well assured.

Temperature Control

From the beginning, the need for accurate temperature control was recognized. It was found that there was a strong tendency on the part of the foundrymen to overheat the metal which invariably resulted in porous castings of inferior strength. A portable pyrometer of the potentiometer type was provided, connected with an iron-constantan thermocouple. The latter was encased in a sheath made of seamless steel tubing, one inch in diameter, with a 1-16 in. wall, closed at the bottom by welding.

Present Practice

The couple is allowed to remain in the bath, and the temperature is observed constantly, from the time melting begins until ready to pour.

When ready to melt, the pot is preheated to a dull red (about 1300 degrees Fahr.) and gates and risers from previous heats to the amount of about 50 per cent of the charge are added. When these are melted, the sheet aluminum scrap is added, as fast as it will melt. While there is unmelted metal in the bath, the temperature remains constant at about 1200 to 1250 degrees Fahr. If the unmelted scrap gets stuck in the upper part of the crucible, the liquid metal at the bottom may easily become overheated, as heat is added rather rapidly during melting. Moreover, unless the end of the thermocouple is immersed a distance of at least six inches, it is likely to give low readings. Special care is therefore necessary to prevent overheating during melting. The sheet scrap is, of course, carefully weighed before charging. When the aluminum is fully melted

the temperature is raised to about 1350 degrees Fahr. and copper scrap is added in small pieces. Being of thin section, the copper scrap dissolves rapidly in the aluminum. The melt is stirred with an iron rod until the copper is completely dissolved and the melt thoroughly mixed. The metal is then allowed to stand for two or three minutes, and is skimmed.

The metal is now fluxed with zinc chloride (commercially pure), using about one ounce per 100 pounds of metal. The salt is placed in a small cup formed in the end of an iron rod or tube, thrust to the bottom of the molten metal, and stirred until the reaction is completed. The metal is again allowed to stand for a minute or two, carefully skimmed, and then immediately poured. The pouring temperature is held between 1325 degrees Fahr. and 1375 degrees Fahr.

Hand ladles of thin pressed steel, previously preheated, are used to transfer the metal from the pot to the molds.

About one to one and one-half hours is required from beginning to melt until ready to pour. A melt generally consists of about 150 pounds of metal, the minimum being 100 pounds. On account of the small size of the castings, about 50 per cent gates and risers are produced.

Molds are required to be ready when the metal is melted, so that the metal will not be held longer than necessary.

All molding work is done by hand, no mechanical equipment being available. Ramming is light, the work is plentifully vented, and risers are used freely. The sand is kept as dry as practicable.

Core Oven

Much difficulty was at first experienced through the unsatisfactory drying of cores in a makeshift core oven. An electrically heated oven was constructed of sheet metal, insulated with magnesia boiler covering, and provided with adjustable vents at top and bottom to insure circulation of air. This furnace requires very little regulation or attention, and the results have well repaid the cost of its construction.

Cores are made from the same sand as is used in molding, with the addition of a commercial binder.

Test Coupons

Inspection of castings for physical properties, porosity, and defects is rigid. Three tensile test coupons are cast with every heat, one being poured respectively from the first, middle and last ladle. Each is poured with a separate gate and riser. They are tested as cast, without machining.

Two types of coupons have been used, as shown in Figs.

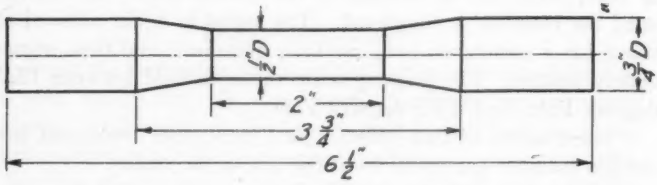

FIG. 5—TEST COUPON USED BY A LARGE PRODUCER OF ALUMINUM ALLOY CASTINGS.

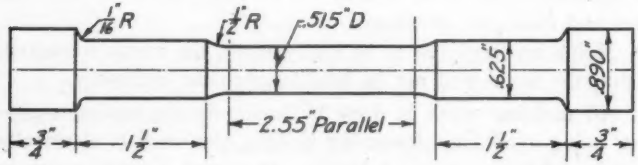

FIG. 6—TENSILE TEST COUPON DIMENSIONS USED IN TESTS.

5 and 6. These coupons are cast to size and are not machined. Fig. 5 is similar to a test coupon used by a large producer of aluminum alloy castings. For the type shown in Fig. 6, split patterns, mounted on a match plate of aluminum sheet, are employed.

There is no appreciable difference in the results obtained from the two types of specimen, but Fig. 6 simplifies molding and testing. A jig is provided in the testing machine which fits the shoulders of this specimen. About a dozen heats were cast using three of each type of specimen to each heat, to de-

termine whether the test results were affected by the form of the specimen. No consistent difference was observed.

Tests

Castings which are to be used in gasoline lines are tested for porosity or leaks by closing all openings with the aid of rubber gasketed clamps and injecting compressed air at a pressure of 10 pounds per square inch, with the casting immersed in water.

As is well known, this alloy has a persistent tendency to porosity, even under the best conditions. About 20 per cent of the castings tested show leaks, but the leaks are generally confined to small pin holes. Such castings may be salvaged by impregnating them with sodium silicate which effectually seals them, and does not interfere with subsequent welding or other

Table I.

Test Results From First Twelve Heats

Specified—Ultimate Tensile Strength (Min.) 18,000 lb. per sq. inch.
Specified—Elongation in 2 inches, 1.5 per cent.

	Specimen No. 1.		No. 2.		No. 3.		
Heat No.	Ultimate Tensile Strength.	Elongation.	Ultimate Tensile Strength.	Elongation.	Ultimate Tensile Strength.	Elongation.	Remarks.
1	18,000	1.0	19,200	1.5	Lost	...	
2	18,100	3.0	18,800	4.0	18,500	4.0	
3	18,800	3.0	18,400	0	.....	...	Rejected for flaws.
4	18,100	3.0	19,000	2.5	22,100	2.0	
5	20,100	3.0	25,000	2.5	21,300	2.5	
6	20,200	3.5	20,200	2.5	20,400	2.5	
7	18,500	1.0	20,700	2.5	20,400	2.0	No. 1 broke at shoulder.
8	21,300	3.0	20,400	2.0	20,900	2.5	
9	18,700	1.5	18,800	1.5	19,200	1.5	
10	21,600	2.5	22,400	1.5	22,000	2.0	
11	20,100	1.5	18,900	1.5	19,000	0.5	Flaw in No. 3.
12	21,000	1.5	20,500	1.5	19,800	1.5	
Aver.	19,540	2.3	20,200	2.0	20,360	2.1	

operations. This treatment is applied, if necessary, after final machining, and the porosity test is then repeated. Castings which have large leaks, permitting free bubbling of air, are remelted. Such cases are few.

Rejections for failure of test specimens to meet physical requirements amounted to seven per cent of the first 100 heats poured. These rejections were mainly due to slightly low tensile strength caused either by overheating of the melt, by failure to mix the solution thoroughly, or by contamination of the scrap

FOUNDRY REPORT

To Metallurgist-

Date _____
Heat No. _____
Specf. _____

Metal Used — Pounds

Gates & Risers (Heat #___) _____
Aluminum Sheet _____
Copper Sheet, etc. _____
_____ _____
_____ _____
_____ _____
Total _____

Melting Record

	Time	Temp.
Start	_____	_____
	_____	_____
Max. Tmp.	_____	_____
Finish	_____	_____
Pour	_____	_____

Test Coupons _____

The following castings were made:

Job Order	Part No.	Passed	Rejected	Remarks

(Signed) _____
Inspector

FIG. 7—FOUNDRY INSPECTOR'S RECORD SHEET.

with other material, and were in the majority of cases traced to careless operation. The tensile test results of the first twelve heats are given in Table I.

Flaws, blowholes or inclusions in the metal are rare.

Inspection

A shop inspector is detailed to the foundry when heats are poured. He checks the weights of metal used, takes temperatures during melting, sees that test coupons are properly poured, identified and delivered for test, inspects castings on the foundry floor, and reports any difficulties or irregularities. Heats are serially numbered and every casting is marked with its heat

number for future identification. The foundry inspector keeps a record of each heat as shown in Fig. 7, and forwards duplicate copies to the chief inspector and metallurgist. Test coupons are pulled within 24 hours, and the results approved before the castings are released to the shop.

Summary

To avoid the delays and difficulties experienced in obtaining, from outside sources, sound aluminum alloy castings of the commonly used commercial grade, eight per cent copper, 92 per cent aluminum, a small foundry was established in a plant where no foundry work had hitherto been done. Only scrap aluminum sheet and copper sheet, tubing, etc., available at the plant, were used. Satisfactory results were obtained through careful temperature control, exclusion of furnace gases, and other simple precautions. The production of aluminum alloy castings of good quality from sheet scrap was found entirely practicable.

Discussion—Aluminum Alloy Castings From Sheet Scrap

By E. Blough, Pittsburgh, Pa.

I have read Mr. Knerr's paper with a great deal of interest and wish to compliment the author on the results obtained, which show that under careful work excellent aluminum castings can be obtained.

There are a few points in the paper upon which I desire to make some comments.

With respect to the utilization of scrap, and this applies to all forms of scrap presenting a relatively large surface, it is the writer's opinion that the mode of procedure used in remelting is an important influence on the final results obtained. For example, it is the writer's experience that in remelting scrap it is advantageous to have a substantial "heel" of molten metal in the bottom of the furnace in which the fresh scrap is immersed

as quickly as possible. If a furnace is charged full of scrap without the presence of such a molten mass of metal the tendency is for a heavy oxidation of the surface before remelting, with the result that the metal when finally melted contains a large amount of skim or dross which is not readily removed, because of its finely divided condition. The condition resulting from this last mentioned procedure results in casting test bars which are full of inclusions with the consequent influence upon the physical properties. It is the writer's opinion that if the former method is pursued, not only with sheet scrap but with other forms of scrap metal, it will result in a materially cleaner product. This procedure, of course, is not to be understood as eliminating the skimming which should always be done after the heat has been fully melted and prior to casting. This procedure is offered as a suggestion for reducing the dross that is always formed during the course of remelting.

Mr. Knerr states another interesting point in connection with the utilization of the sheet steel pot mentioned on page 296, as follows: "An examination of the interior of the pot, after months of use, shows very little attack, and it is evident that little or no iron has been taken up from it by the aluminum." This result is surprising in the face of practical experience which invariably shows that aluminum does absorb iron from an unprotected iron pot, whether it be sheet steel or whether it be cast iron. Just why this particular pot has lasted so long is unexplainable to the writer, although it is the writer's opinion that such performance would not repeat itself very often under practical use of a number of pots made from different lots of steel.

The writer's own experience with sheet steel and with cast iron shows that for practical purposes the cast iron pot is the more satisfactory, although it is necessary to protect the interior surface of the cast iron pot with a lime wash in order to minimize the absorption of iron by the aluminum from the cast iron pot. When this procedure of washing with lime is carefully carried out it is possible to remelt aluminum in such iron pots with a surprisingly small absorption of iron. As an illustration I give below a table showing the results of a test conducted in an

unlimed pot and in a limed pot on starting with metal of the same composition and holding the metal in the molten condition for seven hours, in the case of the limed pot, and eight hours in the unlimed pot, both being maintained at the same temperature. The metal was stirred in each pot thoroughly before taking the samples at the end of each hour period so that all the metal which had been absorbed from the surface of the iron pot during the preceding hour was thoroughly disseminated before sampling. The slight variation in the analyses of the metal contained in the limed pot were probably due to methods of sampling and the ordinary variations of commercial analyses.

Table

Time-Hours	Limed Cast Iron Pot per Cent Iron	Unlimed Cast Iron Pot per Cent Iron
0	.75	.72
1	.73	.81
2	.70	.87
3	.70	.96
4	.80	1.05
5	.73	1.16
6	.73	1.39
7	.73	1.62
8	...	1.73

This table brings out very clearly the benefits to be obtained from applying a lime wash to the interior of cast iron pots, and it also points out what may be expected as regards contamination unless some protective scheme is used.

Discussion—Aluminum Alloy Castings From Sheet Scrap

By Jerome Strauss, Philadelphia, Pa.

The results obtained by Mr. Knerr in somewhat makeshift equipment illustrate the possibilities behind the careful application of sound metallurgical principles to general foundry operations. Although some of the data recorded are difficult to correlate with average practice, such as more troubles in the preparation of the alloy from pig than from scrap with its

greatly increased surface, and also the lack of active reaction between the melt and an unprotected iron container, nevertheless the results are of value not only to the institution whose foundry activities are likely to be as limited as in the case recorded, but to the large operator as well.

The composition of the melts is not stated but values of 3 and 4 per cent elongation on tensile test bars would indicate a copper content somewhat closer to the minimum than to the

FIG. 1—DETAILS OF TEST BAR

maximum limit of the requirement. Obviously, the design of the test bar. not so much in respect to its final dimensions as to the size, nature and location of gate and feeding heads, has a pronounced influence; this information, however, has not been given.

The production of non-ferrous alloys by the re-melting of scrap is a process built upon procedures quite different from those involved in steel furnace operation. The term "scrap" involves, therefore, a somewhat different conception. In the former case, considerable more attention must be given (because

of the limitations of present practices) to the nature of the raw material—its origin, chemical composition, size, surface condition, etc. Manufacturing operations involving the processing of 100 per cent of scrap metals are, therefore, not common and such success as Mr. Knerr has recorded is not frequently chronicled[1].

The writer has had occasion to study the production of an aluminum alloy containing approximately 1.2 per cent copper and 0.9 per cent manganese (balance aluminum plus the usual amounts of silicon and iron) which is regularly produced to meet a specification of 18,000 pounds per square inch tensile strength with 8 per cent elongation in 2 inches. Melting is done in a coal-fired natural draft furnace in open graphite-clay crucibles, the copper and manganese are added as a 55-45 Cu.-Mn. hardener, zinc chloride is used for fluxing and the metal is poured at approximately 1,300 degrees Fahr. Typical results when employing 100 per cent new metal and 100 per cent heads, gates, spillings, defective castings, etc., are given in Table 1.

Table 1

Heat No.	Per cent Scrap	Tensile Strength Pounds per Square Inch	Per cent Elongation in 2 Inches
101	0	20400	11.5
101	0	20600	10.3
226	0	19800	11.0
168	0	19500	8.3
182	0	18800	13.3
307	0	20700	14.0
320	0	19300	13.3
330	0	19700	8.8
157	0	19600	10.5
3783	100	20400	11.8
3783	100	20100	11.3
2834	100	17800	13.8
922	100	19100	13.5
922	100	19900	15.5
1371	100	20700	8.8
1371	100	20900	9.5

Much has been said of the benefit of zinc chloride as a flux and of the evils of too great an addition or of too great a time of contact between it and the melt. It is undoubtedly one of the best mechanical cleansers available to the aluminum foundryman but on clean scrap the following figures show that its effect on tensile properties is often not pronounced and 3 to 5 minute contacts of large amounts with the melt are not deleterious.

[1]P. E. McKinney, *Manganese Bronze*, Trans. A. I. M. E. 1919, p. 421.

Table 2

Heat No.	Zinc Chloride oz. per 100 Pounds Metal	Per cent of Scrap in Charge	Average of Tests Including Flawed Bars: Tensile Str. Pounds per Square Inch	Average of Tests Including Flawed Bars: Elongation Per cent in 2 Inches	Average of Tests Excluding Flawed Bars: Tensile Str. Pounds per Square Inch	Average of Tests Excluding Flawed Bars: Elongation Per cent in 2 Inches
1985	0	100	19950	9.8	20300	10.9
1986	1	100	20000	10.6	20470	11.8
1993	2	100	20250	13.4	20250	13.4
1994	4	100	19500	10.1	20130	11.3
1995	6	100	21830	10.3	21830	10.3
1996	5	100	20600	13.2	20600	13.2

Details of the test bar used in all of the above tests may be had by reference to the attached photograph; the central portion of the test specimen was machined to ½-inch diameter.

Discussion of Aluminum Alloy Castings from Sheet Scrap

By J. B. Johnson, Dayton, Ohio

This paper is a good example of the use of technical control in the foundry to obtain sound castings. It would probably have been more economical to have made up a 50:50 aluminum-copper hardener and used that material in the form of additions to the melt rather than add the copper each time in the form of pure copper, as the melting point of the aluminum-copper hardener is 150 degrees Fahr. below the melting point of pure aluminum.

A New Aluminum Alloy—Alpax*

By Leon Guillet**

Translated from the French by Robert J. Anderson†

Translator's Introductory Note

This paper is a translation of the paper entitled "Un nouvel alliage d'aluminium:l'alpax," written by Dr. Léon Guillet, and which appeared in Le Génie Civil, vol. 82, 1923, pp. 413-419, 441-444. Another paper dealing with the aluminum-silicon alloys by the same author has also been published recently under the title "Les alliages aluminum-silicium et leurs emplois industriels," in Rev. de Mét., vol. 19, 1922, pp. 303-310. This latter paper covers much the same ground as the former, but the former is more complete. A number of papers have appeared in the technical press and have been presented before the societies recently on the aluminum-silicon alloys, and the translator was of the opinion that this paper of Dr. Guillet's, being timely and concerned with a subject now of much interest to the aluminum industry, would be of interest to producers of aluminum-alloy castings. Moreover, the paper presents the subject from the point of view of foreign developments, and it should accordingly supplement knowledge not hitherto available in papers published in the English language.

Certain data and statements appearing in the paper do not appear to be altogether correct, and the paper has been discussed at some length by the translator in an endeavor to clear up certain points.

Introduction

At the recent motor-car and aircraft exhibitions in France there was shown at the booths of two important metallurgical concerns a new aluminum alloy; viz., so-called "alpax," which should be of interest to manufacturers desirous of using an alloy

*This paper appeared originally in the French as Un nouvel alliage d'aluminium: L'alpax, Le Gène Civil, vol. 82, 1923, pp. 413-419, 441-444.

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†Consulting Metallurgical Engineer, Boston, Mass.

of low density and moderately high strength. The problem of producing wrought aluminum alloys having this combination of properties is now fairly well solved, and progress is being made continually in the production of rolled and drawn manufactures which are light and strong. Thus, there are now available to manufacturers the duralumin-type alloys which have excellent properties. Thus, ordinary wrought duralumin has density of 2.7-2.8 and tensile strength of 51,200-56,900 lbs. per sq. in. (36-40 kg. per sq. mm.), and, on the basis of recent British investigations, it is expected that commercial manufactures in duralumin will soon be available, having strength of 71,100-78,200 lbs. (50-55 kg.). While the problem of producing wrought high-strength light aluminum alloys has been fairly well solved, the question of cast high-strength alloys has not been. In the cast condition, ordinary duralumin does not yield the desired mechanical properties, while the heat treatment necessary for enhancing its strength generally gives an alloy heterogeneous as to internal structure. The mechanical properties of cast duralumin are much inferior to those of the wrought alloy.

As is known, the usual light aluminum-casting alloys are only moderately strong. The most common aluminum-casting alloys are (1) binary aluminum-copper alloys, containing up to 15 per cent copper; (2) binary aluminum-zinc alloys, containing up to 30 per cent zinc; and (3) ternary aluminum-copper-zinc alloys, e.g., those with 2-3 per cent copper, 15-18 per cent zinc, and remainder aluminum. The range of tensile properties for these classes of alloys is:

Tensile strength....	17,100-21,300 lbs. per sq. in. (12-15 kg. per sq. mm.)
Elongation	3-0 per cent.

It may be pointed out in passing that certain of the binary aluminum-copper alloys retain their strength fairly well at moderately elevated temperatures, while the zinc-bearing alloys weaken rapidly at increasing temperatures. Of other light aluminum alloys, the binary aluminum-magnesium and aluminum-manganese alloys do not yield especially good results in the cast condition, and, taken by and large, the ordinary commercial light aluminum

casting alloys yield maximum tensile strength of only about 21,300 lbs. per sq. in. (15 kg. per sq. mm.) and elongation of 0-3 per cent. Most of the moderately strong alloys are quite brittle. Substantially pure aluminum (i.e., 99.5 per cent Al), when cast, has tensile strength of 10,000-14,000 lbs. per sq. in. (7-10 kg. per sq. mm.) and elongation of 8-12 per cent.

Preparation of Alpax

The alloy known by the trade name alpax is an aluminum-silicon alloy containing 13.5 per cent silicon and prepared according to certain methods. The mechanical properties of alpax are much better than those of the usual light aluminum-casting alloys. It should be stated at the outset that if this aluminum-silicon alloy is prepared simply by dissolving silicon in aluminum, the mechanical properties are relatively poor, and the resulting alloy is not satisfactory. In order to secure the high mechanical properties which the alloy is capable of attaining, it is necessary to employ a so-called refining process.* The method of refining, as applied to alpax, has been described and patented by Pacz. This process is described briefly below.

The aluminum is first melted and raised to a high temperature, say 1,000 degrees Cent. (Heating to such a high temperature is normally regarded as inadvisable in ordinary foundry melting for the preparation of aluminum alloys). When the aluminum is at a temperature of say 930 degrees Cent., the requisite amount of silicon is added, and then an addition of alkaline salts, preferably alkaline fluorides, is made. The melt is then stirred and allowed to stand. After a short time, a dross, consisting of the melted salts which were added plus alumina, silica, and sodium oxide, forms and rises to the surface. The melt is next skimmed thoroughly to remove all dross, and the alloy is cast at the ordinary temperature, i.e., 710-750 degrees Cent.

This method of preparation confers upon the 86.5:13.5 aluminum-silicon alloy, i.e., alpax, the properties which it is capable of attaining.

*Translator's note: The "refining" of aluminum-silicon alloys is termed "modifying" in the United States.

Aluminum-Silicon Alloys in General

Historical:—Aluminum-silicon alloys are not at all new—they have been studied since the discovery of aluminum. Thus, in 1856, Deville[1]* prepared some aluminum-silicon alloys by heating aluminum in the presence of silicon-chloride vapor; by this method he obtained, e. g., a liquid aluminum-silicon alloy containing 40-50 per cent silicon, in which floated crystals of silicon. Wöhler in 1856, Deville and Debray in 1859, and Rammelsberg in 1869 carried out further work on the alloys and established the fact that intermetallic compounds were not formed in the aluminum-silicon system. In 1891, Minet[2] prepared aluminum-silicon alloys directly by the electrolysis of a bath containing 60 grams sodium chloride, 30 grams sodium-aluminum fluoride, 5 grams alumina, and 5 grams silica.

In 1905, Vigouroux[3] investigated the condition in which silicon occurs in aluminum-silicon alloys and confirmed the conclusion previously reached; viz., that silicon does not form intermetallic compounds with aluminum. Vigouroux stated that the action of hydrochloric acid on aluminum-silicon alloys does not yield hydrogen silicide but that the residue from the reaction is crystalline silicon—this indicating lack of combination between silicon and aluminum. At the same time, he stated that although aluminum and silicon did not normally form intermetallic compounds, the addition of a third element might give rise to definite aluminum silicides. In 1908, Frankel[4] published the first equilibrium diagram of the aluminum-silicon system. In 1911, Kohn-Abrest obtained an alloy corresponding to the formula Al_2Si, by heating aluminum at 1,000 degrees Cent., in a silica crucible; the formula suggested does not, of course, prove the existence of any such compound. In 1911, Frilley[5] published an important paper on metallic silicides and the density of silicon-bearing alloys, dealing in part with aluminum-silicon alloys. His alloys were prepared by the reduction of silica with aluminum borings in an electric furnace, the reaction being similar to that in the thermit process. On the basis of his experiments, Frilley arrived at the following conclusions, among others; (1) aluminum-silicon alloys, containing up to 15 per cent silicon, can be worked hot;

*Numbers refer to papers listed in the appended bibliography.

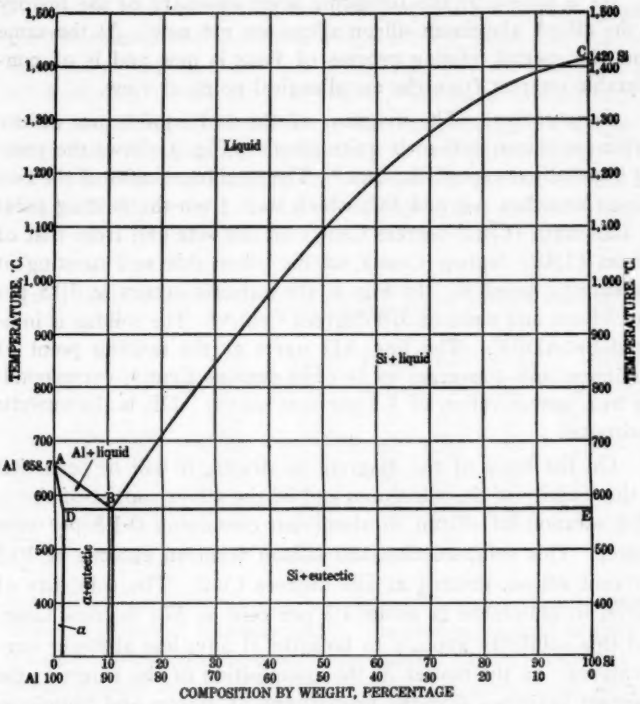

FIG. 1—DIAGRAM OF THERMAL EQUILIBRIUM OF THE ALUMINUM-SILICON SYSTEM

(2) data as to the density of the alloys seem to indicate that the silicon is present as free silicon; at the same time, it seems possible that aluminum silicides, i.e., compounds, might be obtained by direct electrolysis; and (3) silicon increases the strength of aluminum; thus, the tensile strength of the rolled and annealed 97:3 aluminum-silicon alloy is about 15,600 lbs. per sq. in. (11 kg. per sq. mm.), and the elongation is 29 per cent; the tensile strength of the rolled and annealed 90:10 aluminum-silicon alloy is about 21,600 lbs. per sq. in. (15.2 kg. per sq. mm.), and the elongation is 18 per cent.

As is shown by the foregoing brief summary of the history of the alloys, aluminum-silicon alloys are not new. At the same time, the special refining process of Pacz is new and is of considerable interest from the metallurgical point of view.

Constitution:—The diagram of thermal equilibrium of the aluminum-silicon system is quite simple. Fig. 1 shows the present generally accepted diagram.* The liquidus consist of the two curved branches AB and BC, which start from the melting point of aluminum (658.7 degrees Cent.) on one side and from that of silicon (1,420 degrees Cent.) on the other side and meeting at the eutectic point B. In Fig. 1, the eutectic occurs at 10.5 per cent silicon and melts at 570 degrees Cent.** The solidus is indicated by ADBE. The line AD starts at the melting point of aluminum and converges to D (570 degrees Cent.), corresponding to a concentration of 1.5 per cent silicon. DE is the eutectic horizontal.

On the basis of the diagram as drawn, it will be seen that in the vicinity of the aluminum end of the alloys consist of the α solid solution of silicon in aluminum containing 0-1.5 per cent silicon. This solid solution and silicon form an eutectic at 10.5 per cent silicon, melting at 570 degrees Cent. The solubility of silicon in aluminum is about 1.5 per cent at 570 degrees Cent., and this solubility appears to be little, if any, less at lower temperatures. In the matter of the composition of the eutectic; the diagram indicates that the proportions of silicon and aluminum in this eutectic are given by the relation 1:11.8. Thus, the eutectic is lean in silicon and rich in the aluminum-silicon solid solution, and it is, therefore, relatively malleable.

Properties:—In order to make definite comparison between the properties of refined and unrefined aluminum-silicon alloys, the writer first made a series of tests to determine the properties of the ordinary (unrefined) alloys with increasing percentages

*Constructed by the translator from the data of Roberts[14] and Rosenhain[15]. It should be stated that Dr. Guillet shows a diagram, in his original paper, which is somewhat different from the one in Fig. 1.

**Dr. Guillet gives the eutectic as occurring at 11.5 per cent silicon and melting at 570 degrees C., and in discussing Fig. 1 here his original text has been altered to conform with the figure. Dr. Guillet points out that the placement of eutectic composition at 10.5 per cent silicon is erroneous, and he lays emphasis on the point that there is contradiction between such placement and the microstructure of the alloys (cf. also translator's discussion).

of silicon. Assuming that the forms of the equilibrium diagram for the refined and unrefined alloys are the same, the following conclusions can be drawn off hand; viz., (1) the aluminum-rich solid solution (0-1.5 per cent silicon) will have substantially the same properties as aluminum, with, doubtless, some change in the tensile strength and elongation; (2) alloys consisting of the solid solution and eutectic (i.e., 1.5-10.5 per cent silicon) will have their elastic limit and tensile strength increased with increas-

Table 1.

MECHANICAL PROPERTIES OF HOT ROLLED ALUMINUM-SILICON ALLOYS; UNREFINED.

Composition of alloy, elements per cent			Yield point, lbs. per sq. in.	Tensile strength, lbs. per sq. in.	Elongation per cent	Reduction in area, per cent	Brinell hardness[b]	Charpy impact resistance, kg.m. per sq. cm.,	Angle[a]
Al[a]	Si	Fe							
98.12	1.19	0.69	7,100	15,600	30	68.1	36	9.4	bent
97.64	1.70	0.66	6,500	15,900	30	68.1	37	9.4	bent
95.74	3.40	0.86	10,000	19,100	21	47.6	44	6.2	155
93.98	5.15	0.87	10,000	19,200	22	48.6	44	5	144
92.69	7.31	....	11,100	16,200	22.5	49.7	31	3.2	171
90.25	9.75	....	12,100	24,600	17.5	45.5	38	2.6	172
86.85	13.15	....	11,400	21,900	18	37.7	46	1.3	172
83.60	16.40	....	10,100	23,300	18	28.3	48	2.4	173

[a]Aluminum, by difference. [b]1,000 kg. load, 10 mm. ball.

ing silicon, at least if they are homogeneous and not contaminated by oxides; in these alloys, the elongation and impact resistance should decrease with increasing silicon; and (3) the hyper-eutectic alloys (i.e., those containing more than 10.5 per cent silicon) should have poorer mechanical properties with increasing silicon.

Some tests were made on unrefined aluminum-silicon alloys drawn at 425-450 degrees Cent. These alloys were prepared simply by adding solid silicon to liquid aluminum. The aluminum used contained 99+ per cent Al, while the silicon contained 94.4 per cent Si, 2.3 Al, 2.1 Fe, and 1.1 per cent Ca. (0.1 per cent not determined). Analysis was made of the resultant alloys for iron and silicon. The series of alloys varied in composition in the range 1.19-16.40 per cent silicon, remainder aluminum (cf. Table 1). Mechanical tests were made on these alloys under the following conditions:

1. Tensile test, on round bars, 13.8 mm. diameter and 100 mm. gage length.

2. Brinell hardness, 1,000 kg. load, 10 mm. ball.

3. Notched bar impact test, Charpy machine, on 10x10x55 mm. bars, rounded notch 2x2 mm.

The results of these tests are given in Table 1.

It should be pointed out that the last alloy (i.e., the one containing 16.40 per cent silicon) was very heterogeneous, and in the cast ingot from which drawn, the silicon content of the upper part was considerably higher than that of the lower. Thus, in the original ingot which was 100 mm. diameter and 400 mm. high, the silicon content of the top was 18.61 per cent and that of the bottom was 14.26 per cent; the composition aimed at was 15 per cent silicon. It might be concluded from this that

Table 2.

MECHANICAL PROPERTIES OF CAST ALUMINUM-SILICON ALLOYS; UNREFINED.

Composition of alloy, elements per cent. Al[a]	Si	Yield point, lbs. per sq. in.	Tensile strength, lbs. per sq. in.	Elongation per cent	Reduction in area, per cent	Brinell hardness[b]	Charpy impact resistance, kg.-m. per sq. cm.
98.80	1.20	17,800	22,200	2	5.9	50.5	0.6
98.30	1.70	19,500	23,500	2.5	8.7	60.5	0.5
96.60	3.40	22,600	22,600	2	7.3	61	0.3
94.87	5.13	22,000	22,500	3.5	5.9	59	0.2
92.70	7.30	(?)	13,200	2	(?)	34	2
90.05	9.95	(?)	17,800	3	(?)	44.5	2.5
87.85	12.15	(?)	21,800	1.2	(?)	62	1.6

[a]Aluminum, by difference. [b]1,000 kg. load, 10 mm. ball.

in the case of hyper-eutectic alloys the silicon (density 2.4, as against 2.7 for aluminum) rises on solidification, thus causing non-homogeneity. This might, of course, be expected, since in the hyper-eutectic alloys the silicon is the pro-eutectic constituent, and during the course of freezing silicon would precipitate out first and continue precipitating out on cooling as the mother metal became more concentrated towards the eutectic composition.

Tests were next made on the mechanical properties of cast unrefined alloys. The test pieces were cast coupon with the ingots for drawing (i.e., the ingots drawn in the tests described above). Hence, the worked and cast alloys had substantially the same compositions.* Table 2 gives a summary of the results obtained on the cast alloys. The data may be compared with those in Table 1.

*Translator's note: It is not stated whether the alloys were chill cast or sand cast, but presumably they were chill cast. There will be noted some variations in the silicon content of the drawn and cast alloys (cf. Tables 1 and 2).

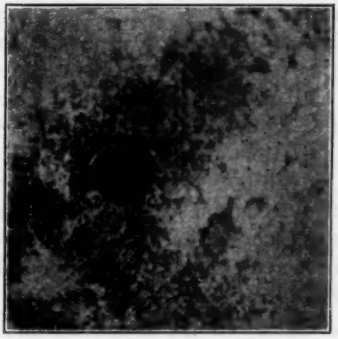

FIG 2—86.5:13.5 ALUMINUM-SILICON ALLOY; UNREFINED; SHOWING PIPE; MACROGRAPH; ACTUAL SIZE.

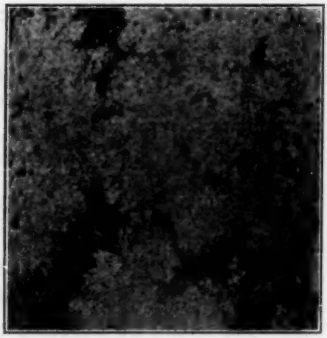

FIG. 3—SAME AS FIG. 2; SHOWING GROSS MACROSTRUCTURE; BUT X 6.

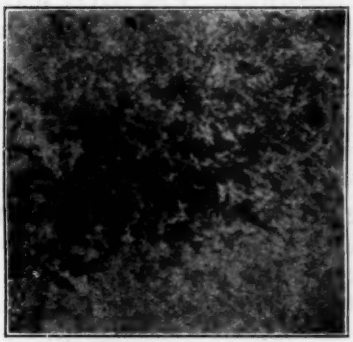

FIG. 4—86.5:13.5 ALUMINUM-SILICON ALLOY; REFINED (ALPAX); SHOWING PIPE; MACROGRAPH; ACTUAL SIZE.

FIG. 5—SAME AS FIG. 4; SHOWING GROSS MACROSTRUCTURE; BUT X 6.

As has been pointed out, the maximum solid solubility of silicon in aluminum is 1.5 per cent, and the existence of this solid solution indicates that quenching may have some influence in affecting the amount of free silicon present in the alloys.** Some tests were made to determine the effect of quenching on the prop-

**Translator's note: Since the solid solubility of silicon is apparently but little, if any, affected by temperature, quenching could have but little, if any, effect on the amount of free silicon present in originally stable and homogeneous alloys, and consequently on the properties.

erties of a series of alloys. Samples of hypo-eutectic alloys were quenched from 475 degrees Cent. in water at 20 degrees Cent. Table 3 gives comparative figures for the mechanical properties of the alloys in the annealed and quenched conditions. These mechanical tests were made after the samples had stood for 48 hours at the ordinary temperature after the heat treatment. Referring to the data of Table 3, it will be seen that the effects of quenching are, in general, slight. The tensile strength is increased slightly, while the elongation and reduction in area vary irregularly. The impact resistance is increased somewhat by quenching, but the yield point is decreased rather markedly.

As would be expected the density of the aluminum-silicon alloys decreases slightly with increasing silicon content. Table 4 gives some figures for the theoretical density and the density as found for three alloys. The theoretical density was calculated, using 2.7 for the density of aluminum and 2.4 for that of silicon. It should be stated that the aluminum employed in making up these alloys was relatively impure.

On the basis of tests made by the writer and those of other investigators, it may be concluded that the maximum tensile properties of unrefined aluminum-silicon alloys cannot exceed,

For worked alloys,

Tensile strength, 22,800-24,200 lbs. per sq. in. (16-17 kgs. per sq. mm.)

Elongation, 17-18 per cent.

Charpy impact resistance, 2-3 kg.-m. per sq. cm.

For cast alloys,

Tensile strength, 21,300-22,800 lbs. per sq. in. (15-16 kgs. per sq. mm.)

Elongation, 2-3 per cent.

Charpy impact resistance, 0.5-1.0 kg.-m per sq. cm.

The Aluminum Alloy Alpax

Definition has been given previously as to what is understood by the aluminum alloy alpax. The alloy is characterized not only by its silicon content but also by the refining process which is necessary in order to confer upon it the desired properties. Re-

fining can also be applied to alloys containing percentages of silicon different from that in alpax (i.e., 13.5 per cent silicon), and it is apparently desirable for all hypo-eutectic alloys.

It is of interest to discuss the effect of the refining process on the structure of the alloys. If the aluminum-silicon eutectic alloy, prepared without refining, be examined, it will be found to be heterogeneous, as has been pointed out. Large isolated grains of silicon exist in such an alloy, and there is a strong tendency toward segregation when cast into ingots, i.e., the silicon content of the top of a cast ingot is higher than that in the bottom. It has been shown experimentally that large grains of free silicon and segregation in cast ingots are not found in the alloy when refined.

Macroscopic examination is useful in showing the difference between refined and unrefined aluminum-silicon alloys. Refining has a marked effect upon the character of the pipe formed in cast ingots. Thus, in refined alloys, the depth of pipe in circular ingots, e.g., 100 mm. diameter and 400 mm. high, is less and the piped volume is more scattered than in unrefined alloys.* In unrefined alloys the pipe pocket is surrounded with large crystals of silicon, while in refined alloys the structure is more homogeneous. Figs. 2 to 5, inclusive, are macrographs, taken on refined and unrefined 86.5:13.5 aluminum-silicon alloy, which show the nature of the pipe and the gross macrostructure.

Refining has noticeable effect upon the hardness of aluminum-silicon alloys, particularly upon the uniformity of hardness in given examples. Thus, if brinell-ball impressions are made at a number of successive points across the surfaces of polished samples, it is found that the hardness values are much more regular for refined than for unrefined alloys. Thus, the following ranges of hardness values have been found for 86.5:13.5 aluminum-silicon alloy; viz., for unrefined alloy, brinell hardness number = 46-53; and for refined alloy, brinell hardness number = 53-57.

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*Translator's note: While tests have not been made as to the comparative contraction of refined and unrefined aluminum-silicon alloys, apparently there may be some difference in the values, since refining affects the character of pipe (cf. paper by the translator[50] on the contraction of aluminum alloys).

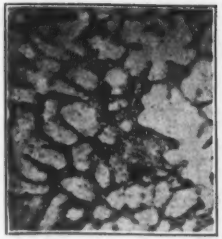

FIG. 6—ALUMINUM-SILICON ALLOY; 5.01 PER CENT SILICON; REFINED: UNETCHED: X 57.

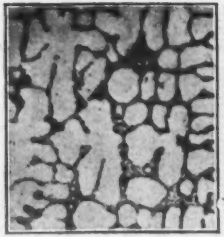

FIG. 8—ALUMINUM-SILICON ALLOY; 5 PER CENT SILICON; UNREFINED: UNETCHED: X 57.

FIG. 10—ALUMINUM-SILICON ALLOY: 9.8 PER CENT SILICON; UNREFINED:ETCHED $NaOH$: X 200.

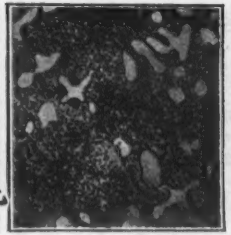

FIG. 12—ALUMINUM-SILICON ALLOY: 12.72 PER CENT SILICON: UNREFINED: UNETCHED: X 57.

FIG. 14—ALUMINUM-SILICON ALLOY: 12.76 PER CENT SILICON: UNREFINED; UNETCHED: X 57.

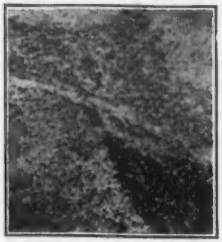

FIG. 7—SAME AS FIG. 6: BUT X 430.

FIG. 9—SAME AS FIG. 8: BUT X 430.

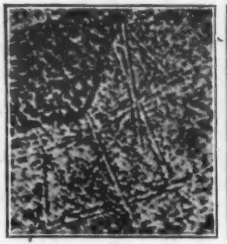

FIG. 11—SAME AS FIG. 10: BUT X 500.

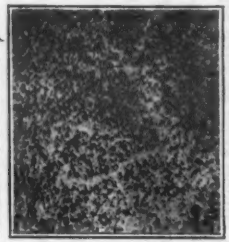

FIG. 13—SAME AS FIG. 12: BUT X 430.

FIG. 15—SAME AS FIG. 14: BUT X 430.

While macrographic examination is useful in showing the difference in structure between the refined and unrefined alloys, this is really not necessary, since simple fracture of rather large ingots (because the rate of cooling evidently has considerable influence upon segregation) readily shows the difference. On fracture, large crystals of silicon are found in the center of unrefined ingots, while the grain is fine and regular in the case of refined ingots.

Microstructure:—Microscopic examination readily shows the difference between refined and unrefined aluminum-silicon alloys. Examination of alloys with increasing percentage of silicon up to the eutectic composition (and exceeding 1.5 per cent silicon) shows increasing amounts of eutectic, as would be expected from the diagram of thermal equilibrium. In the hypo-eutectic alloys of composition between 1.5 and 10.5 per cent silicon, the structure consists of the eutectic plus the aluminum-rich aluminum-silicon solid solution (solid solution α; cf. Fig. 1). The photomicrographs of Figs. 6-15, inclusive, show the structures of refined and unrefined aluminum-silicon alloys, in the range of about 5 to 13 per cent silicon. These micrographs are self-explanatory.

The segregation which occurs in cast ingots with respect to the silicon content at the top and bottom is shown by the micrographs of Figs. 16 and 17. Fig. 16 shows the structure of a section cut from the top of a cast ingot 100 mm. diameter and 400 mm. high, which had an average silicon content of 16 per cent. Fig. 17 shows the structure of a section cut from the bottom of the ingot. In Fig. 16 the structure consists of the eutectic plus large grains of free silicon, while in Fig. 17, it consists of the eutectic plus the aluminum-silicon solid solution.

Figs. 18 and 19 show the microstructure of the eutectic alloy unrefined, while Fig. 20 shows the structure of alpax (i.e., the 86.5:13.5 aluminum-silicon alloy, refined). The difference in structure is extraordinarily marked. The structures in Figs. 18 and 19 consist of the eutectic plus large plates of silicon, while that in Fig. 20 consists of a very fine eutectic structure.

Nature of the Refining Process:—As has been pointed out, aluminum-silicon alloys prepared by direct electrolysis of a suitable mixture of salts have structures similar to those of the alloys

FIG. 16—ALUMINUM-SILICON ALLOY: TOP OF INGOT: UNREFINED: ETCHED NaOH: X 68.

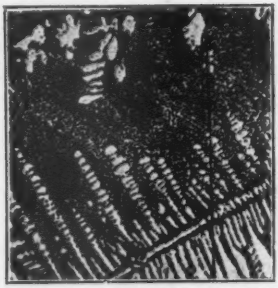

FIG. 17—ALUMINUM-SILICON ALLOY: BOTTOM OF INGOT: UNREFINED: ETCHED NaOH: X 68.

FIG. 18—ALUMINUM-SILICON ALLOY: EUTECTIC COMPOSITION: UNREFINED: UNETCHED: X 165.

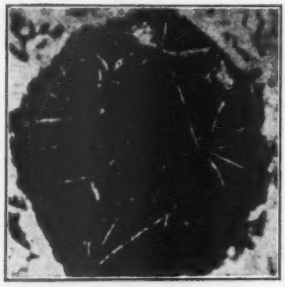

FIG. 19—SAME AS FIG. 18: BUT X 430.

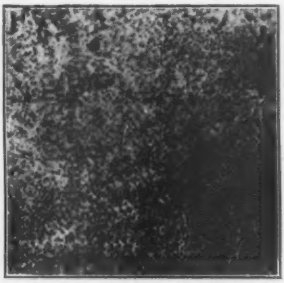

FIG. 20—86.5:13.5 ALUMINUM-SILICON ALLOY: REFINED (ALPAX): UNETCHED: X 200.

which have been refined by Pacz's process; moreover, similar structures are obtained when the alloys are made by the method of Wöhler, i.e., reduction of potassium-silicon fluoride by aluminum. It is of especial interest to state that the refined alloys lose their characteristic structure on remelting, and the refining process should be applied on remelting scrap in foundry practice.

While the present writer was quite sceptical at first regarding the alleged effects of the refining process, the desirable effects of the processes can now be affirmed. The question naturally arises: What is the correct explanation of the refining action? One conclusion seems certain; viz., the addition of the alkaline salts has the effect of dissolving the alumina and silica, which can exist in the unrefined alloys, causing them to pass into the dross. Moreover, it appears that when the salts are added the silicon is wetted more easily* by the aluminum and consequently is dissolved more easily. Jeffries[10] and Curran[11] attribute the principal rolé in the refining action to the alkaline fluoride. A small amount of sodium is set free, silicon fluoride is formed, and the sodium dissolves in the aluminum. Curran has obtained the normal structure of the refined alloys by adding a small amount of sodium to liquid aluminum-silicon alloys, and he concludes that a ternary aluminum-silicon-sodium alloy is formed, whose normal structure is similar to that of refined alloys. He recognizes, however, that the addition of sodium may not be detected in the final alloy, but the influence of its presence is found in the altered microstructure.

It seems logical to the present writer to believe that the effect of adding a strong reducing agent like sodium is to reduce the oxides (alumina and silica) present in the bath. For the present, the precise action in refining cannot now be explained, despite recent investigations, e.g., that of Edwards,[12] who indicates that the addition of modifying agents, characterizing the production of refined alloys, very markedly affects the composition and melting point of the eutectic. It might very well be asked whether refining has not simply the effect of preventing segregation. If so, then it would be deduced that the ordinary

*Translator's note: This is equivalent to saying that addition of alkaline salts changes the surface tension of the liquid aluminum.

unrefined alloy is not normal (i.e., is really the modification), while the refined alloy is the normal one. However this may be, it is certain that true alpax, i.e., refined 86.5:13.5 aluminum-silicon alloy, is a true eutectic. This indicates that the equilibrium diagram, as shown, may be wrong.

It might also very well be asked whether the refining treatment does not also modify the hypo-eutectic alloys. Offhand, it would seem not, and this also applies to the hyper-eutectic

Table 3.

MECHANICAL PROPERTIES OF WORKED ALUMINUM-SILICON ALLOYS; UNREFINED; ANNEALED AND QUENCHED.

Composition of alloy, etc. ments per cent		Condition of alloy	Yield point, lbs. per sq. in.	Tensile strength, lbs. per sq. in.	Elongation, per cent	Reduction in area, per cent	Brinell hardness[b]	Charpy impact resistance, kg.m. per sq. cm.	Angle[a]
Al[a]	Si								
98.81	1.19	Annealed	7,100	15,600	30	68.1	36	9.4	bent
98.81	1.19	Quenched	5,100	16,600	27	64.4	40	9.9	bent
98.30	1.70	Annealed	6,500	15,900	30	68.1	37	9.4	bent
98.30	1.70	Quenched	4,700	17,200	29	64.7	40	11.8	bent
96.60	3.40	Annealed	10,000	19,100	21	47.6	44	6.2	155
96.60	3.40	Quenched	5,800	19,800	24	53.7	58	7.5	128
94.85	5.15	Annealed	10,000	19,200	22	48.6	44	5	144
94.85	5.15	Quenched	7,500	20,600	24	49.7	51	6.9	140

[a]Aluminum, by difference. [b]1,000 kg. load, 10 mm. ball.

Table 4.

THEORETICAL AND ACTUAL DENSITY OF THREE ALUMINUM-SILICON ALLOYS.

Composition of alloy, elements per cent		Actual density gms. per c.c.,	Theoretical density gms. per c.c.,
Al[a]	Si		
98.3	1.7	2.65	2.676
90.4	9.6	2.64	2.67
87.7	12.3	2.63	2.66

[a]Aluminum, by difference.

alloys in which free silicon exists as the excess substance. These latter alloys are not useful, incidentally, for mechanical construction purposes. These matters will, however, be discussed more fully in later paragraphs of this paper.

The amount of salts used in refining is small—3 per cent, and it is of interest to state that a small increase in the amount of salts added causes slight diminution in the properties of the alloy.

Mechanical Properties.—Some figures obtained as to the mechanical properties of unrefined aluminum-silicon alloys have

already been given in Tables 1 to 3, inclusive. The ordinary results obtained for an alloy containing about 12 per cent silicon are as follows:

For cast alloy,

Yield point.....17,900 lbs. per sq. in. (12.6 kg. per sq. mm.).
Tensile strength .....22,200 lbs. per sq. in. (15.6 kg. per sq. mm.).
Elongation .....2.2 per cent.
Reduction in area....5.9 per cent
Brinell hardness .....50.5.
Charpy impact resistance .....0.6 kg.-m. per sq. cm.

For worked alloy, annealed,

Yield point.....11,400 lbs. per sq. in. (8 kg. per sq. mm.).
Tensile strength .....21,900 lbs. per sq. in. (15.4 kg. per sq. mm.).
Elongation .....16 per cent.
Reduction in area ....37.7 per cent.
Brinell hardness 46
Charpy impact resistance .....1.3 kg.-m. per sq. cm.

Some data are given in Table 5 for the mechanical properties of alpax, aluminum, and three common light aluminum

Table 5.

COMPARISON OF THE MECHANICAL PROPERTIES OF ALPAX, ALUMINUM, AND THREE ALUMINUM ALLOYS.

Composition of alloy	Cast			Rolled or drawn					
				Tensile strength, lbs. per sq. in.		Elongation, per cent		Brinell hardness[c]	
	Tensile strength, lbs. per sq. in.	Elongation, per cent	Brinell hardness[c]	Annealed	Cold worked	Annealed	Cold worked	Annealed	Cold worked
Alpax, 11-14 per cent Si[a]	25,600-32,700	5-10	60	22,800	42,700	30	5	60	..
92:8 Al-Cu.....	17,100-21,300	1-2	60	28,400	42,700	20	10	60	90
88:2:10 Al-Cu-Zn.	17,100-24,200	2-4	55	28,400	42,700	20	10	55	90
Duralumin	....	....	..	54,000	59,700	20	15	60	150
Aluminum[b]	.....	....	..	14,200	28,400	30	5	30	60

[a]Remainder aluminum. [b]Commercial. [c]500 kg. load, 10 mm. ball.

alloys, in the cast and worked conditions. Data are not given for the properties of cast aluminum and duralumin. Duralumin does not attain its best properties except when heat treated, and the usual heat treatment applied to wrought duralumin does not give noteworthy results in the case of the cast alloy. As already pointed out, cast substantially pure aluminum has tensile strength of 10,000-14,000 lbs. per sq. in. (7-10 kg. per sq. mm.) and elongation of 8-12 per cent, or more, depending upon the pouring temperature. As will be noted in Table 5, cast alpax

Table 6.

TENSILE PROPERTIES OF SAMPLES OF ALPAX (a).

Yield point, lbs. per sq. in.	Tensile strength, lbs. per sq. in.	Elongation, per cent	Reduction in area, per cent	Modulus of elasticity lbs. per sq. in.
15,900	29,600	7	8	13,900,000
14,900	28,000	9	9	13,500,000
15,600	28,700	8	9	12,100,000
17,200	29,700	8	10	11,900,000
17,400	29,300	7	9	13,500,000
16,200	27,900	10	10	12,500,000

[a]Tests by Czochralski.

has the highest strength and elongation of the alloys listed; viz., 25,600-32,700 lbs. per sq. in. (18-23 kg. per sq. mm.), with elongation of 5-10 per cent. The properties of cast alpax are better than those of the rolled and annealed alloy. While most alloys are, of course, stronger when worked and annealed than when cast, it appears that either mechanical treatment itself or reheating before rolling or other working has a deleterious effect upon the properties of alpax. Whether refined or unrefined, the cast aluminum-silicon alloys have about the same properties as the worked alloys.

Table 6 gives the results of some tests made by Czochralski[12] on cast alpax (test bars or castings), which serve to indicate the excellent mechanical properties of the alloy.

Tests have been made to determine the effect of refining on the mechanical properties of hypo-eutectic alloys, and Table 7 gives some comparative data for the mechanical properties of a series of refined and unrefined alloys. It will be seen from these data that refining has considerable effect upon all the mechanical properties of the alloys, except upon the strength and hardness of the alloy containing about 5 per cent silicon.

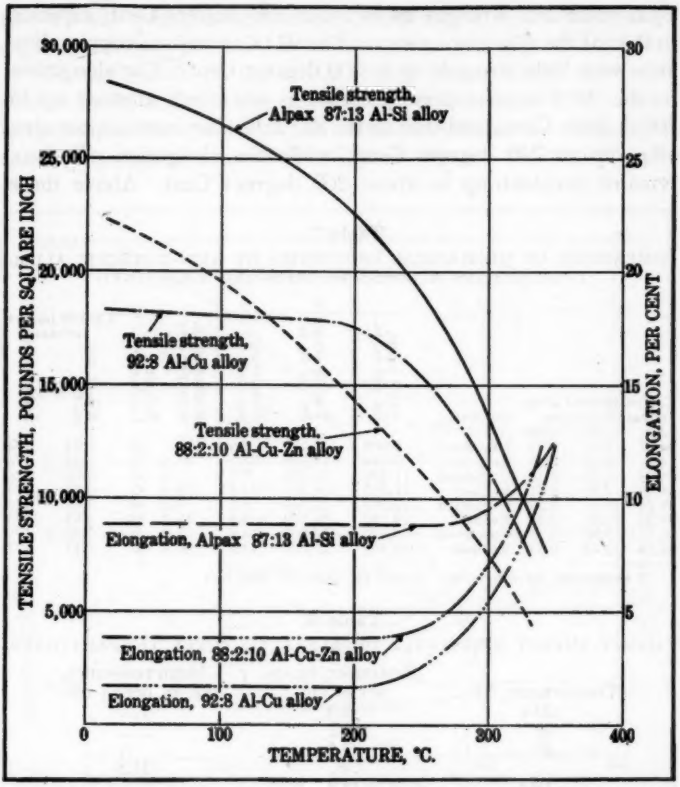

FIG. 21—TENSILE STRENGTH AND ELONGATION OF THREE CAST ALUMINUM ALLOYS AT ELEVATED TEMPERATURES (CZOCHRALSKI)

While it has been shown that the mechanical properties of the aluminum-silicon alloys are quite good at the ordinary temperature, it is of interest to have information concerning their properties at high and low temperatures. Tests have been made by Czochralski[12] on the effect of increasing temperatures upon the strength of alpax and other aluminum alloys, and Fig. 21 shows the effect of elevated temperatures upon the strength and elongation of cast alpax, 92: 8 aluminum-copper alloy, and 88: 2:10 aluminum-copper-zinc alloy. Fig. 21 shows that cast

alpax maintains strength up to about 350 degrees Cent. superior to that of the other two alloys. The 92:8 aluminum-copper alloy loses very little strength up to 200 degrees Cent. The elongation of the 92:8 aluminum-copper alloy is not much affected up to 200 degrees Cent., and that of the 88:2:10 aluminum-copper-zinc alloy up to 240 degrees Cent., while the elongation of alpax remains constant up to about 260 degrees Cent. Above these

Table 7.

COMPARISON OF MECHANICAL PROPERTIES OF HYPO-EUTECTIC ALUMINUM-SILICON ALLOYS; REFINED AND UNREFINED

Composition of alloy, elements per cent			Condition	Yield point, lbs. per sq. in.	Tensile strength, lbs. per sq. in.	Elongation per cent	Reduction in area, per cent	Brinell hardness[b]	Charpy impact resistance	
Al[a]	Si	Fe							Kg.-m. per sq. cm.	Angle°
94.57	5.0	0.43	Unrefined	9,800	19,100	5.9	15	40	0.83	174
94.49	5.12	0.39	Refined	9,400	19,500	12.5	20.6	39	0.85	170
91.85	7.79	0.36	Unrefined	11,200	19,800	7.9	9.0	40	0.02	176
91.19	7.30	0.51	Refined	21,100	25,200	14.8	13.4	46	0.55	171
89.24	10.43	0.33	Unrefined	12,500	17,900	8.8	9.0	48	0.01	177
89.35	10.31	0.34	Refined	14,100	26,500	9.9	23.2	52	0.55	173
86.72	12.76	0.52	Unrefined	16,500	23,900	11.6	12.8	56	0.08	179
86.74	12.72	0.54	Refined	18,500	27,200	13.0	18.1	53	0.15	177

[a] Aluminum, by difference. [b] 1,000 kg. load, 10 mm. ball.

Table 8.

CHARPY IMPACT RESISTANCE OF ALPAX AT THREE TEMPERATURES.

Temperature, ° C.	Resistance, kg.-m. per sq. cm.	Mean resistance, kg.-m. per sq. cm.
20	8.9	....
20	16.2	....
20	9.4	....
..	....	11.5
—180[a]	11.3	....
—180[a]	7.4	....
—180[a]	6.4	....
.....	....	8.35
300[b]	9.1	....
300[b]	13.0	....
300[b]	9.4	....
....	....	10.5

[a] Sojourn of 15 hrs. in liquid air.
[b] Temperature maintained for 15 mins.

respective temperatures the elongations of the three alloys rise rapidly. Fig. 22 shows the effect of increasing temperature upon the strength and elongation of rolled aluminum and duralumin. The curves may be compared with those in Fig. 21. It may be

pointed out that the mechanical properties of rolled alpax are superior to those of rolled aluminum up to 300 degrees Cent.

In the matter of the effect of low temperatures upon the properties of alpax; some tests have been made by the writer to determine the hardness and impact resistance at both high and low temperatures. Table 8 gives figures for the Charpy

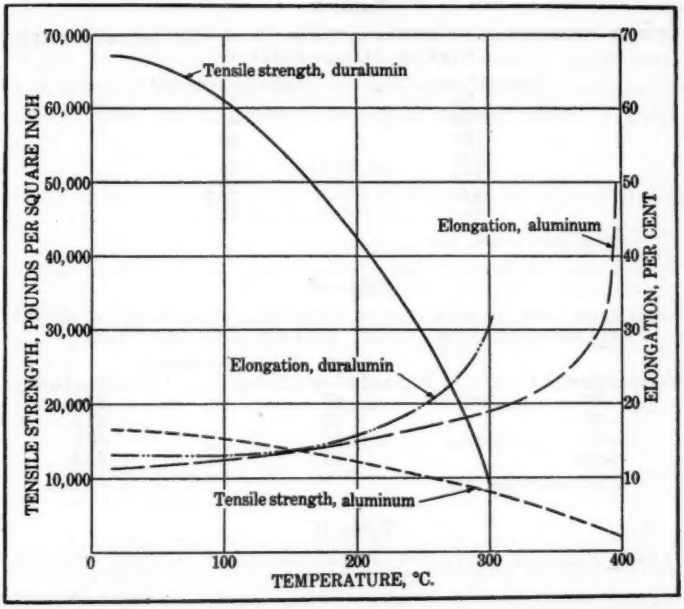

FIG. 22—TENSILE STRENGTH AND ELONGATION OF ROLLED ALUMINUM AND DURALUMIN AT ELEVATED TEMPERATURES (CZOCHRALSKI)

impact resistance at three temperatures, which may be found of interest. These tests were made on un-notched bars, 20x20x80 mm. Evidently, on the basis of these tests, temperature, whether high or low, within the range indicated, does not have much effect on the impact resistance. Brinell-hardness tests were made on alpax at elevated temperatures with the results shown in Table 9. Brinell-hardness tests were also made on the refined and unrefined alloy at low temperatures, with the results in

Table 10. The data in the tables are self-explanatory, and it may be noted that refining apparently has no effect upon the retention or increase in hardness at either high or low temperatures. The hardness falls markedly with increasing temperature and rises markedly with decreasing temperature (i.e., at temperatures much depressed below room temperature).

Table 9.

EFFECT OF INCREASING TEMPERATURES UPON THE BRINELL HARDNESS OF ALPAX; REFINED.

Temperature, ° C.	Brinell hardness[a]
18	52
100	45
150	40
200	34
250	28
300	23.5
350	18

[a] 500 kg. load, 10 mm. ball.

Table 10.

EFFECT OF LOW TEMPERATURES UPON THE HARDNESS OF 86.5:13.5 ALUMINUM-SILICON ALLOY; REFINED AND UNREFINED.

	Brinell hardness[a]	
Temperature, ° C.	Refined alloy (alpax)	Unrefined alloy
20	57	53
—20	63	61.5
—75	74	66.5
—180	95	88.8

[a] 500 kg. load, 5 mm. ball.

Table 11.

JANNIN FRICTION TESTS[a] ON ALUMINUM-SILICON ALLOYS; REFINED AND UNREFINED

Composition of alloy elements per cent.		Condition of alloy	Speed of shaft, r.p.m.	Mean diameter of ball, impression in 10th of a mm.
Al[b]	Si			
87	13	Refined	774	1.14
87	13	Unrefined	798	1.15
90	10	Refined	810	1.17
90	10	Unrefined	818	1.26
92.5	7.5	Refined	822	1.35
92.5	7.5	Unrefined	814	1.50
95	5	Refined	822	1.59
95	5	Unrefined	820	1.55

[a] Condition of tests: shaft, quenched case-hardened steel; duration of test, 5 min.; pressure, 16,280 kgs.; lubrication, pure castor oil, 30 drops per min.; oil, at 18° C.

[b] Aluminum, by difference.

Data on the frictional resistance of alloys are useful in considering certain practical applications, and the new Jannin machine[8] is useful for making friction tests. Tests have been made, using this machine, of the friction, i.e., resistance to wear, of a series of refined and unrefined aluminum-silicon alloys with the results given in Table 11. As shown, refining does not seem to have much influence on the frictional resistance, but wearing away under the action of friction does, however, increase with increasing percentage of silicon. In the tests summarized in Table 11, lubrication was used; some tests were made without lubrication, but the data are not included here because the results were not satisfactory owing to the formation of burrs.

Table 12.

COMPARISON OF SOME PHYSICAL PROPERTIES OF ALPAX, ALUMINUM, AND THREE ALUMINUM ALLOYS[a].

Composition of alloy	Density, gms. per c.c.	Electrical conductivity, microhms per cm.	Thermal expansivity [c]	Thermal conductivity, gm.-cals. per cm,[3] per 1° per sec.
Alpax, 11-14 per cent Si[b]	2.5-2.65	26.5×10^{-4}	0.0000222	0.366
91:9 Al-Cu	2.85-2.9	..	0.0000245	0.348
88:2:10 Al-Cu-Zn	2.9-2.95	..	0.0000255	0.308
Duralumin	2.8	20×10^{-4}	0.0000226	.....
Aluminum, commercial	2.7	33×10^{-4}	0.0000251	0.470

[a] Based on Czochralski.
[b] Aluminum, by difference.
[c] Increase in length per cent of length per degree Cent.

Attention should be directed to the effect of impurities on the properties of alpax. The principal impurity is iron, derived from the original silicon and aluminum. It is essential that the iron content of alpax should not exceed 0.8 per cent, and it should preferably be not more than 0.5-0.6 per cent, since otherwise the elongation is seriously reduced. The copper content should preferably be not more than 0.5-0.6 per cent, since otherwise elongation again falls off. Investigation of the effect of other impurities has not been made.

Physical Properties:—Certain of the physical properties of alpax have been determined by different investigators. Table 12 gives some data published by Czochralski[12] on the properties of alpax, aluminum, and three aluminum alloys. Some deter-

minations have been made recently in France with the following results; viz., density, 2.60-2.64; coefficient of thermal expansion, 21.6×10^{-6}; and specific electrical resistance, 4.6 microhms per cm.[3] at 20 degrees Cent. The very complete investigation by Edwards[13] contains many data for the density of several of the alloys at various elevated temperatures, but owing to lack of space these cannot be included here. Edwards indicates that the coefficient of thermal expansion between 20 and 577 degrees Cent. is 23.5×10^{-6}, that of aluminum being 29×10^{-6}. The density of alpax is considerably less than that of the usual commercial aluminum alloys, and the coefficient of thermal expansion is also lower.

The solidification shrinkage of alloys (i.e., the amount of contraction on passing from the liquid state to the solid state) is of great importance in founding. The shrinkage of aluminum is 0.204 in. per ft. (1.7 per cent = 17 mm. per m.), that of the 92:8 aluminum-copper alloy is 0.150 in. per ft. (1.25 per cent = 12.5 mm. per m.), while that of alpax is 0.132 in. per ft. (1.1 per cent = 11 mm. per m.). Thus, the shrinkage of alpax is relatively small, being of the order of cast iron. It is important to bear in mind that the contraction of alpax is small, since the contraction of most of the usual casting alloys is rather high.

Corrosion:—As is well known, the corrosion of aluminum alloys by various media is of much importance in considering different alloys for specific industrial applications. Unfortunately, tests made for corrodibility are not always reliable, and the results are liable to be in error. Figs. 23 and 24 show graphically the loss in weight of alpax, aluminum, and some alloys on corrosion in concentrated nitric acid, as determined by Czochralski[12]. The curves are self explanatory, and it is of interest to note that cast alpax is much more resistant to corrosion in this medium than are the three other materials. However, the loss in weight of rolled alpax is greater than that of rolled aluminum and duralumin.

Investigation in the laboratory of the Metallbank und Metallurgische Gesellschaft has shown that the corrosion of cast products by sulphuric and nitric acid is greater than of rolled products; this is, of course, general and does not apply to alpax alone. In the case of a large number of corroding solutions, alpax ap-

proaches aluminum in its resistance to attack, and accordingly this alloy is generally superior to other commercial aluminum alloys from the point of view of corrodibility. However, alpax (and aluminum also) is more easily attacked by alkaline solutions than certain other alloys, e.g., aluminum-copper alloys.

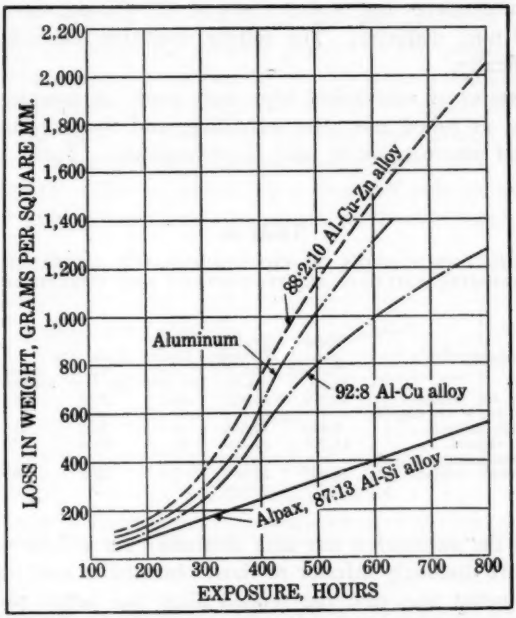

FIG. 23—LOSS IN WEIGHT IN CONCENTRATED NITRIC AND OF CAST ALPAX, ALUMINUM, AND TWO ALLOYS (CZOCHRALSKI)

At the same time the resistance of alpax to corrosion by sea water is particularly high, and this alloy presents a real superiority over other aluminum alloys in applications where sea mist and water are encountered.*

Rolled and Drawn Alpax:—It has already been pointed out that alpax is especially suitable for the production of castings and that it does not have exceptional properties when rolled or

*Translator's note: The question of the use of aluminum-silicon alloys for marine purposes has recently been discussed by Hewlett and Basch[23].

otherwise worked. Some tests have been made in order to obtain further information on the mechanical properties of the alloy when worked. Two lots of rolled 86.5:13.5 aluminum-silicon alloy were prepared at the works of the Société Métallurgique de la Bonneville. One lot was refined (being consequently alpax) and the other was unrefined. Ingots were cast 100 mm. diameter and broken down at 425-450 degrees Cent. to bars 20 mm. diameter. The rolling operation did not present any difficulty.

A series of mechanical tests were made on samples of the two lots, as rolled and after annealing, and the materials were examined macroscopically and microscopically. Table 13 gives

Table 13.

MECHANICAL PROPERTIES OF HOT-WORKED AND ANNEALED 86.5:13.5 ALUMINUM-SILICON ALLOY; REFINED AND UNREFINED.

Condition of the samples	Yield point, lbs. per sq. in.	Tensile strength, lbs. per sq. in.	Elongation per cent	Reduction in area, per cent	Brinell hardness	Charpy impact resistance, kg.-m. per sq. cm.
As drawn; not refined.....	13,200	21,500	13.5	20.7	45	0.8
Annealed 1 hr. at 350 degrees Cent.; not refined.....	9,400	19,800	14	23.3	43	1.0
As drawn; refined.....	14,200	23,300	10	24.6	48	1.0
Annealed for 1 hr. at 350 degrees Cent.; refined.....	10,800	22,900	7.6	28.3	46	1.3

some of the mechanical-test data obtained. As will be seen, the results are distinctly inferior to those obtained in cast alpax. It will be noted also that the refined alloy has better properties than the unrefined. Annealing, for the time and at the temperature employed, has the effect of decreasing the tensile strength and elongation, while the impact resistance, although originally small, is slightly increased. It may be concluded, as has been done on the basis of previous tests, that mechanical treatment has a detrimental effect upon certain qualities of alpax.

Macroscopic examination of these two lots of alloys showed plainly the difference in structure between the refined and unrefined products, as is the case with cast alloys. The worked alloys showed rather large amounts of free silicon and of the aluminum-silicon solid solution. Normal cast alpax consists

ordinarily of a fine eutectic structure, with, at times, a little free aluminum-silicon solid solution. At the same time, the eutectic portion of the two worked alloys did not present the same aspect; the unrefined alloy had a more coarse eutectic, as contrasted with a very fine eutectic in the refined product. However, in both these alloys, there was found not only the aluminum-silicon solid solution, in addition to the eutectic, but also grains of free silicon. Fig. 25 shows the eutectic portion in the refined worked alloy. Macroscopic examination of the original ingots showed nicely the existence of segregation in the two alloys as cast.

On the basis of the foregoing then, an entirely different conclusion is arrived at from that held hitherto; viz., while refining has the effect of producing a very fine eutectic structure, there is segregation in cast ingots of sufficiently large size (or

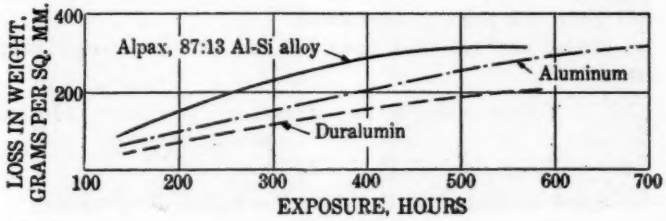

FIG. 24—LOSS IN WEIGHT IN CONCENTRATED NITRIC ACID OF ROLLED ALPAX, ALUMINUM, AND DURALUMIN (CZOCHRALSKI)

what amounts to the same thing, when the rate of cooling is sufficiently slow) so that free silicon and the aluminum-rich solid solution separate out in relatively large masses. Certain properties of the alloy are lowered because of this larger state of division of the constituents, as contrasted with the typically fine eutectic structure of alpax. This conclusion seems to the present writer to be of especial importance. Thus, in a practical way, it will obviously not be possible to exceed a certain size in the production of castings for parts or ingots for rolling, drawing, or other working, without accelerating the rate of freezing, since otherwise in castings of too large cross section serious segregation will be produced which will have harmful effects on the

properties of the manufactures. Apparently, the size of casting to be made in sand will have to be limited, or else the rate of cooling will have to be accelerated, as is done, for example in the production of aluminum bronze. It should be stated that heat treatment has no effect in overcoming the bad effects of segregation, and the effects of segregation in a cast ingot will be seen in the finished product. In the matter of wrought alpax, therefore, it appears that the thermal treatment prior to rolling does not destroy the properties of the alloy, but any deterioration in properties, as compared with cast alpax, should be traced to segregation in the original ingot.

Tests have been made on the effect of rolling and annealing temperatures on the properties of alpax, and it has been found that the best rolling temperature is 475 degrees Cent. Reduction of 50 per cent may be made at this temperature. In rolling, the temperature may be ± 50 degrees Cent. from the temperature just given, for practical operations.

Rolled and annealed alpax has the following tensile properties:

Tensile strength .....22,800 lbs. per sq. in. (16 kgs. per sq. mm.).
Elongation .....28-30 per cent.

Hard worked alpax has the following tensile properties:

Tensile strength .....35,600 lbs. per sq. in. (25 kgs. per sq. mm.).
Elongation .....5 per cent.

In order to obtain an alloy having maximum ductility (30 per cent elongation), it is necessary to anneal at about 350 degrees Cent. This temperature may be varied ± 50 degrees Cent.

Coalescence on Prolonged Anneal:—The general question of the mechanical working of alpax has been discussed previously, and it has been indicated that the belief that ordinary heating prior to working and working itself are deleterious to the properties of the alloy, is erroneous. It might be thought that heating prior to working might have a harmful influence, if sufficiently extended, by causing coalescence of the constituents. It accordingly seemed advisable to the writer to make

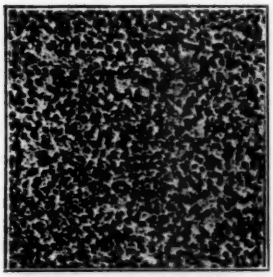

FIG. 25—EUTECTIC PORTION, IN DRAWN ALPAX; UNETCHED: X 200.

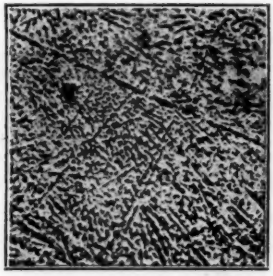

FIG. 26—ALPAX: AS CAST: UNETCHED: X 500.

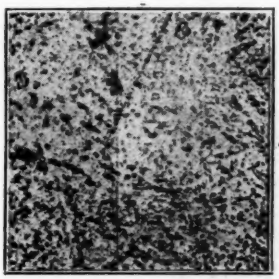

FIG. 27—ALPAX: ANNEALED FOR 4 HRS. AT 550° C.: UNETCHED: X 500.

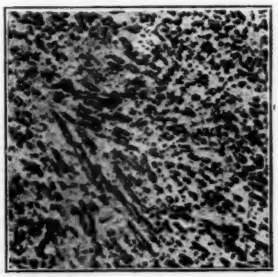

FIG. 28—ALPAX: ANNEALED FOR 12 HRS. AT 550° C.: UNETCHED: X 200.

systematic study of the effect of prolonged annealing on the microstructure and hardness of the alloy. Two samples of alpax were heated in a salt bath for 4 hours at 450 degrees Cent. and for periods varying from 1 to 12 hours at 550 degrees Cent. The microscopic observations made are recorded in Table 14, and the effects of the heatings are shown in the micrographs of Figs. 26-31, inclusive.

The data in Table 14 are self explanatory. Figs. 26-29, inclusive, show microstructures of the first alloy, as cast, after heating for 4 hours at 550 degrees Cent, and after heating for 12 hours at 550 degrees Cent. Figs. 30 and 31 show microstructures of the second alloy, as cast, and after heating for 12 hours

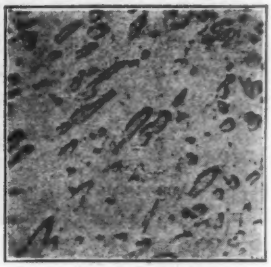

FIG. 29—SAME AS FIG. 28: BUT X 500.

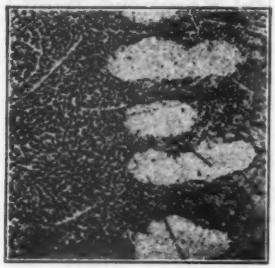

FIG. 30—ALPAX: AS CAST: UNETCHED: X 200.

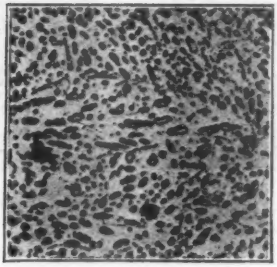

FIG. 31—ALPAX: ANNEALED FOR 12 HRS. AT 550° C.: UNETCHED: X 200.

at 550 degrees Cent. On the basis of the data in Table 14 and the accompanying micrographs, it is clear that alpax has a tendency to coalesce on heating, but for the phenomenon to be very marked, it is necessary to anneal for a fairly long time and at high temperature. In practice, it is accordingly advisable not to exceed 450 degrees Cent. in heating for breaking down ingots, if the heating must be somewhat prolonged. When coalescence is thorough, the hardness of alpax is considerably decreased.

Machining:—Experiments have been carried out recently at the Metallbank und Metallurgische Gesellschaft which have defined the best conditions for machining alpax.

Turning does not present any special difficulty, at least when suitable speed is used. Turning may be done well with a speed of 656 ft. per min. (200 m.), rate of feed of 0.0138 in. (0.35 mm.), and depth of cut of 0.1378 in. (3.5 mm.). Threading is done best with an angle of 70°-85° and a speed of cut of about 16.4 ft. per min. (5 m.). It is advisable to use a tap with four cutters, with an angle of cut of 60°. Threading should be done under lubrication and not dry. Drilling is rather difficult,

Table 14.

EFFECT OF ANNEAL ON THE HARDNESS AND COALESCENCE OF ALPAX.

Heat treatment		Alloy No. 1		Alloy No. 2	
Time hrs.	Temperature °C.	Microstructural aspect	Brinell hardness	Microstructural aspect	Brinell hardness
As cast		Eutectic, nearly pure	58	Eutectic + a little aluminum	54
4	450	Coalescence, starting	51	Coalescence, starting	53
1	550	Coalescence, starting	46	Coalescence, starting	47
4	550	Coalescence, marked	42	Coalescence, marked	40
8	550	Coalescence, very marked	39	Coalescence, very pronounced	40
12	550	Coalescence, very marked	40	Coalescence, very pronounced	39

at least with American drills. The best results have been obtained with ordinary drills, but having an angle of crown of about 80°. The feed in drilling should not exceed 0.0142 in. (0.36 mm.), and at a speed of 98 ft. per min. (30 m.). It is advisable to rough drill holes and then finish with two cuts with a well sharpened reamer.

Milling is done well at speeds between 197 and 492 ft. per min. (60-150 m.) and feeds of 0.0118-0.0315 in. per turn of miller (0.3-0.8 mm.). The milling cutter should have rectilinear teeth, as those with helical teeth give poor results. Milling should always be done under lubrication. The best lubricants for milling alpax are mixtures of soap and water or oil and water. The oil-water mixtures are best for milling at high speed.

In passing, it may be stated that the autogenous welding of

alpax has been studied, and it may be pointed out that zones of weakness are set up at welded junctures as in the case of aluminum. Alpax may be coated with metals and also electroplated with copper or nickel as in the case of aluminum.

Special Alpax Alloys:—As has been explained, alpax is the aluminum-silicon alloy containing 13.5 per cent silicon which is modified by a special refining process, e.g., that of Pacz. It might be asked whether special alloys having the properties of alpax could not be made by substituting for part of the aluminum a binary solid solution, e.g., aluminum-copper or aluminum-zinc solid solutions rich in aluminum. Some special alloys have

Table 15.

MECHANICAL PROPERTIES OF CAST AND ROLLED SPECIAL ALUMINUM-SILICON ALLOYS, COMPARED WITH ALUMINUM-COPPER AND ALUMINUM-ZINC ALLOYS

Composition of alloy, elements per cent				Yield point, lbs. per sq. in.	Tensile strength, lbs. per sq. in.	Elongation, per cent	Reduction in area, per cent	Brinell hardness	Charpy impact resistance, kg.-m. per sq. cm
Al[a]	Si	Cu	Zn						
					Cast alloys.				
87.9	12	1.1	..	22,600	22,600	2	7.3	60	0.3
85	12	3	..	29,900	29,900	(?)	(?)	84	0.2
82	13	5	..	26,900	26,900	1	5.9	73	0.2
93	..	7	..	.....	19,100	...	...	85	0.2
97	..	...	3	20,000	30,300	2.2	7.3	70	0.5
95	..	...	5	20,800	32,300	3	7.3	74	0.3
93	..	...	7	22,800	22,800	0.6	4.5	72	0.2
90	..	...	10	.....	28,300	0.8	4.5	78	0.2
					Rolled alloys.				
87.9	12	1.1	..	17,100	49,100	9.5	34.3	..	3
85	12	3	..	10,000	34,700	10	20.4	..	1.2
82	13	5	..	19,900	28,400	4	(?)	..	0.6
93	..	7	..	22,900	40,100	6	16.8	..	0.6
97	..	...	3	16,500	27,200	14.5	27.1	..	1.2
95	..	...	5	17,900	29,700	13	23.3	..	1.2
93	..	...	7	21,300	34,000	14	20.7	..	1.2
90	..	...	10	22,500	33,100	4	(?)	..	1.2

[a]Aluminum, by difference.

been made by the writer in which copper and zinc were added to aluminum-silicon alloys, and a summary of some tests made on these is given in Table 15. As will be noted, the results are rather irregular, but the cast alloys are not any better than ordinary alpax.* Most of the rolled special alloys do have better properties than ordinary rolled aluminum-silicon alloys, but a good alloy for rolling has the nominal composition 87 :1 :12 aluminum-copper-silicon.

*Translator's note: Some tests have been made by Dix and Lyon[23] on the mechanical properties of sand-cast aluminum-copper-silicon alloys.

Industrial Applications of Alpax

As has been explained, alpax is suitable primarily for the production of castings. While it can be cast readily in either sand molds or chill molds, a few precautions may be given as to manipulation. On casting in chill molds, the mold temperature ought to be held rather high, i.e., about 500 degrees Cent. This is considerably higher than the temperature employed ordinarily for aluminum alloys; viz., 200 degrees Cent. However, the temperature of the mold should not be too high, since then

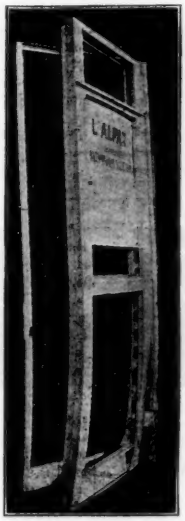

FIG. 32—DOOR OF RAILWAY CAR, CAST IN ALPAX

the alloy would crystallize coarsely and be very brittle. Alpax is cast in dry-sand molds in the case of thin or irregular castings, but when the coring is complicated green-sand molds are employed. When using green-sand molds, the mold may be skin dried on the face by the flame of a welding torch. The sand used for molds is the same as that ordinarily employed for casting bronze. Graphite may be added to the sand mix in making up cores.

In preparing alpax the alloy is melted in graphite-clay crucibles, heated to above 900 degrees Cent., and the refining salts added in the amount of 3 per cent. The salts are stirred in with a graphite rod, and then the resulting dross is skimmed off. The melt is next cooled, and then poured at 600-700 degrees Cent., depending upon the size of the casting. It should be emphasized that the melt should not be allowed to stand at high temperature after the refining operation. Gates, risers, and other scrap may be used in the amount of 40-50 per cent with new metal in making up heats.

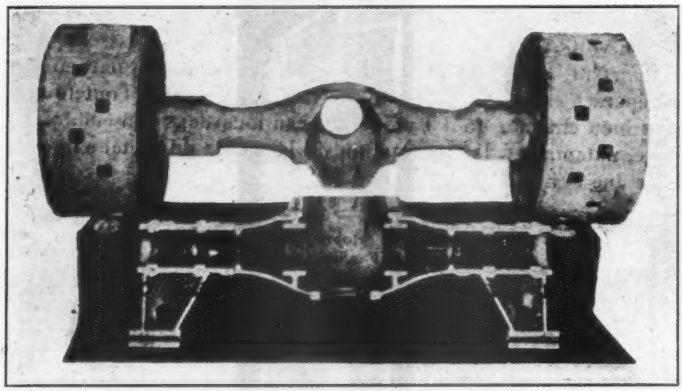

FIG. 33—REAR AXLE HOUSING AND WHEELS FOR MOTOR BUS, CAST IN ALPAX: WEIGHT OF HOUSING 150 LBS. (70 KG); WEIGHT OF EACH WHEEL 189 LBS. (86 KG.)

Referring to specific applications of alpax; tests made on alpax pistons for internal-combustion engines indicates that the alloy is superior to the ordinary 90:10 aluminum-copper alloy, because the thermal expansivity of the former is less. The ordinary clearance used for cast iron is suitable for alpax, and with such clearance no slap occurs. Tests have been made on alpax connecting rods, cylinder blocks (with and without iron liners), and on rear-axle housings, and the results have been quite encouraging. Castings have also been made in the alloy for parts of railway cars, and Fig. 32 shows a door and frame for a railway car cast in alpax.

Of course, when cast alpax is substituted for steel in specific applications, it is necessary to increase the dimensions considerably. Thus, it has been pointed out by de Fleury[7], who has been engaged in the production of alpax parts, that in the case of rear-axle and differential housings for motor cars, the sections should be increased in the proportion of 1:1.7. However, even with this increase, very marked savings in weight can be effected by the use of alpax in place of steel. According to de Fleury, if alpax be substituted for iron and steel in the cylinder blocks, axle housings, and some minor parts, an ordinary car weighing 770 lbs. (350 kgs.) will weigh 10 per cent less.

A set of alpax castings for the rear-axle housing and wheels of a motor bus is shown in Fig. 33. This was cast by the Forges de Crans for the Société des Transports, which operates in the Paris district. These parts have been put into regular service, after satisfactory tests. The gain in weight by using these parts in place of cast steel parts is 562 lbs. (225 kgs.).

It is apparent that the field of application of alpax is quite wide, without consideration of the applications already made. Some precautions are, of course, necessary in making new applications, and consideration should be given to the necessity for increasing the size of sections when substituting the alloy for iron or steel parts.

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**Translator's note:* A number of other papers, not cited by Dr. Guillet, dealing with aluminum-silicon alloys, have been published, and a list of the more important ones are given, Nos. 14-21.

Discussion—A New Aluminum Alloy

By Robert J. Anderson, Boston, Mass.

This paper by Dr. Guillet, which has been translated by the writer, should be of especial interest because of the numerous data presented as to the mechanical properties of aluminum-silicon alloys and also because it reflects late European developments in the use of these alloys for castings. The information presented should be found of interest by foundrymen and metallurgists engaged in the production of aluminum-alloy manufactures.

It should be stated at the outset that the alloys under discussion are not referred to as alpax in the United States, and there is certainly nothing to be gained by fastening trade names and catch terms on alloys. It seems to the writer more logical to talk about aluminum-silicon alloys than to use such terms as alpax, aladar, silumin, etc., as is done abroad in discussing aluminum-silicon alloys.

There are a number of items in the present paper which call for discussion, and these are taken up briefly below.

In the first place, Dr. Guillet states in line 7, page 310, that the density of duralumin is 2.7-2.8. Now, conceivably, the density of some duralumin-type alloys, e.g., aluminum-copper-magnesium-silicon alloys rather lean in copper and high in magnesium and silicon, might be as low as 2.7. However, the density of ordinary simple duralumin is certainly not 2.7, but rather 2.8. Dr. Guillet also states in line 17, page 310, that the heat treatment of cast duralumin yields a heterogeneous product. The quenching heat treatment of duralumin does give rise to unstable equilibrium in the alloy, but it would undoubtedly be less heterogeneous than as cast.

On page 310, it is stated that the range of tensile strength for various light aluminum-casting alloys is some 17,100-21,300 lbs. per sq. in., with elongation of 3-0 per cent. These figures are obviously incorrect. The range of tensile strength of commercial light aluminum-casting alloys is much wider. Thus, the

strength of the 70:30 aluminum-zinc alloy, sand cast, is some 38,000 lbs. per sq. in. In lines 4 and 5, page 311, and elsewhere the elongation given for cast aluminum is too low and the tensile strength is too high, i.e., the figure 14,000 pounds.

Referring to the method used for the so-called refining of the 86.5:13.5 aluminum-silicon alloy, described on page 311, it may be pointed out that in the United States, the refining process, so-called by Dr. Guillet, is termed modifying the alloys. The ordinary alloys made up by adding silicon to aluminum are termed normal alloys (the unrefined alloys of Guillet), while the alloys when treated with an alkaline fluoride, or otherwise, are termed modified alloys. In passing, it may be of interest to add that the patents taken out by Pacz bearing on the treatment of aluminum-silicon alloys include the following: English Pat. Nos. 158,827, Jan. 26, 1921; 160,426 and 160,427, Mar. 18, 1921; Canadian Pat. No. 209,696, Mar. 22, 1921; and U. S. Pat. Nos. 1,387,900, Aug. 16, 1921, and 1,464,625, Aug. 14, 1923. In essence, the method of Pacz calls for the modification of the normal aluminum-silicon alloys by treatment in the liquid state with a flux consisting of an alkaline fluoride, preferably sodium fluoride, plus an alkaline chloride or an alkaline-earth fluoride. The flux is placed on top of the liquid alloy and stirred in. It should also be added that a process for the modification of silicon-bearing aluminum alloys has been patented by the Aluminum Co. of America (cf. English Pat. Nos. 171,996 and 171,997, Nov. 15, 1921; and 172,018, Nov. 23, 1921; and U. S. Pat. No. 1,410,461, Mar. 21, 1921). The process calls for treating liquid alloys with 0.05 per cent of sodium or potassium, or both. Addition of sodium disperses the silicon and thus modifies the alloys.

On page 312, the work of Vigouroux on the condition of silicon in aluminum is cited. According to Vigouroux, the silicon was regarded as occurring in the free state in aluminum-silicon alloys, and he points out that this is proved by the fact that attack of the alloys by hydrochloride acid yields a residue which contains the silicon. It is now known on the basis of work at the National Physical Labratory and elsewhere that silicon exists in several forms in aluminum-silicon alloys; viz., (1) as a solid solution in the aluminum; (2) as free silicon forming

an eutectic with the aluminum-silicon solid solution; (3) as free silicon in excess in hyper-eutectic alloys; (4) as FeSi, probably; and (5) as (AlFeSi)X — the complex compound of Merica. When aluminum-silicon alloys are dissolved, as in ordinary chemical analysis, it frequently happens that part of the silicon is unattacked and is determined in the residue as free silicon, while part is oxidized and is determined as silica, SiO_2. It has been shown that the silicon which is oxidized to silica is that part which had existed in the state of the aluminum-rich aluminum-silicon solid solution, while that which is determined as free silicon had existed as crystals of free silicon in the alloy (cf. Rosenhain, Archbutt, and Hanson[16], cited in the supplementary bibliography).

In the matter of the work of Frilley, cited on pages 312 and 313, on the tensile properties of wrought aluminum-silicon alloys, attention might very well be directed to the experiments of Schirmeister (reference cited in the supplementary bibliography to the paper), who has rolled alloys containing 0.5-18.8 per cent silicon.

Regarding the diagram of thermal equilibrium shown in Fig. 1; the writer has taken liberties with Dr. Guillet's paper and replaced his diagram with another one. It was felt, however, that the diagram used lent itself to discussion better, and the text was accordingly changed with appropriate footnote remarks so as not to alter the opinion of Dr. Guillet regarding the position of the eutectic. The diagram, as given, refers to the normal (i. e., unrefined) alloys, and it would certainly be useful if a diagram would be completely worked out using modified (i.e., refined) alloys. There is considerable difference of opinion as to the precise placement of the eutectic in both the normal and modified alloys. Different investigators have placed the composition in the normal alloys at from 9.5 to 11.6 per cent silicon, while the composition in the modified alloys has been placed at from 13 to 15 per cent silicon. The melting point of the eutectic is also given as from 570 to 578 degrees Cent.

Attention should be directed to the tensile properties of the cast unrefined alloys given in Table 2. The results are certainly most curious, and it is difficult to believe, for example,

that strength as high as 22,200 lbs. can be obtained in cast 98.8:1.2 aluminum-silicon alloy.

In lines 2 to 5, page 326, it is stated that cast duralumin does not give noteworthy results when heat treated. Now, it is well known that suitable heat treatment, when applied to cast duralumin-type alloys, does enhance the mechanical properties very materially, and Dr. Guillet's statement apparently should be modified.

Referring to Fig. 22, the strength given for rolled aluminum at 400 degrees Cent. is evidently too low.

There are some other items which require explanation, but these are apparent, and do not require discussion here.

It may be pointed out that the high-tenor aluminum-silicon alloys, e.g., 87:13 aluminum-silicon, are not being used extensively in the United States. Difficulties with machining have retarded their wider employment. The 95:5 aluminum-silicon alloy is used considerably by the General Electric Co. for sand castings, and interesting ternary aluminum-copper-silicon alloys have been developed in the United States recently and are being used to some extent. In preparing aluminum-silicon alloys, the silicon can be introduced as elemental silicon of high purity, or in the form of intermediate alloys, e.g., 50:50 aluminum-silicon. One of the most valuable properties of the alloys is their relatively low contraction on freezing, and this is explained by the fact that silicon expands on freezing. It has generally been held that the yield point of the aluminum-silicon alloys is rather low, and it is of interest to direct attention to the high values shown by Dr. Guillet for this property.

Discussion—Alpax, a New Development of Aluminum Alloys

D. BASCH: This paper was written about a year ago, and the aluminum and silicon situation has made enormous strides since then, so that some of the data given in Mr. Guillet's paper are out of date. I do not believe that a great deal can be gained by going through the paper in detail. The greatest advantage will be obtained undoubtedly if, after this session, you gentlemen sit down in your quite study and take these two

papers on aluminum silicon alloys, and study them and compare the data and draw your own conclusions. I simply want to bring out a few points here which may be of interest. I think, first, we owe a duty to Dr. Pacz, to bring out as clearly as possible the point that the modification process is to be credited entirely to his endeavors and Dr. Guillet brings that point out in his paper.

I do not believe that Mr. Guillet's theory that the modifying agent simply acts as a scavenger, as a cleanser, is correct. The theory is unsettled. He contradicts himself to a certain extent when he says, in the next paragraph, "It might also very well be asked whether the refining treatment does not also modify the hypo-eutetic alloys. Offhand, it would seem not, and this also applies to the hyper-eutetic alloys in which free silicon exists as the excess substance. These latter alloys are not useful, incidentally, for mechanical construction purposes." If there was a cleansing action in the modifying agent, it certainly ought to have an effect on the alloys of lower silicon content just the same as on the alloys of higher silicon content. Another point brought out in Dr. Guillet's paper is the fact that the properties of cast alpax are better than those of the rolled and annealed alloy, while most alloys are of course stronger when worked and annealed than when cast, it appears that the mechanical treatment itself, or reheating before working or other work, has a deleterious effect upon the properties of alpax. At this point it is particularly important, because in the application of these alpax alloys for navy work, for instance, we will have to use high silicon castings to carry hot oil or any other media at temperatures around 200 degrees Cent., continuously, and of course, the fact must be very definitely established that a service of this sort will not gradually destroy the physical properties which make the use of alpax possible at the start. I think these are about the most important features brought out in the paper.

S. Daniels: I think it can be said very freely that both processes seem to do the same thing, more or less. To me it seems that the use of metallic sodium has one disadvantage, and that is the handling of it. We find that we have to keep it under a liquid or something before we can use it. The metallic sodium can be used at a lower temperature than the fluorides, and that may be an advantage. May I ask whether or not antimony will not accomplish the same effect as sodium in that alloy? I have heard it stated that it would, and I wonder whether I could get any accurate information on that.

D. Basch: Yes, the patent application of the Aluminum Company specifies antimony and bismuth as a refining agent, and they claim particularly that the use of antimony and bismuth will arrest the reversal of the modification. We ourselves have no positive information on that, but you would be able to find the data on that, I suppose, from Edwards & Jefferies. They have a patent application on antimony and bismuth.

Foundry Treatment and Physical Properties of Silicon-Aluminum Sand Castings

By D. Basch and M. F. Sayre, Schenectady, N. Y.

The last four years have seen the development of a series of silicon alloys of aluminum with high physical properties, and even better, with exceptionally good foundry properties. A very low shrinkage coefficient, freedom from hot shortness, and very high fluidity combine to permit the casting of large and intricate sections not previously attempted, and to reduce materially the difficulties in handling simple sections. With these is found to be present a relative freedom from porosity and a good resistance to atmospheric corrosion. On the other hand, certain disadvantages limit their field of usefulness. An exhaustive investigation of these alloys carried on by the General Electric Co. has been followed by their use by the company on an increasing scale. These alloys are bound to be of increasing importance, and it is felt that a description covering particularly their physical properties and foundry technique, and the modifications necessary when changing to these alloys from others, will be of value.

Summarizing briefly, these silicon alloys may be divided into two groups—one with silicon content running up to 8 per cent, and the other with silicon content 8 to 15 per cent, with better physical properties, but requiring while in the liquid state a special modifying treatment to be of value. Copper additions operate to increase the hardness, the proportional limit, and the tensile strength, while decreasing the ductility and resistance to atmospheric corrosion. These copper silicon alloys may well be listed as a third group.

These three groups correspond to three natural fields of usefulness. The second group gives an exceptional combina-

tion of properties; high strength and ductility, good resistance to atmospheric corrosion, and good foundry properties, but calls for high grade raw material and for a certain amount of extra manipulation in the foundry, and uses a patented process on which royalty must be paid. Alloys of this class go by the proprietary names "Silumin" in France and Germany, and "Alpax" in this country. The "Willmill" alloys recently introduced in England also are of this type. Where this high strength is not needed, as in the great run of ordinary casting work, the lower silicon alloys would be used. The copper silicon alloys occupy a midway field and would be used where somewhat higher strength and hardness is needed than furnished by the unmodified silicon alloys, but where resistance to atmospheric corrosion, or high ductility, is not required.

Physical Properties

A—Strength and Ductility

The alloys in the first group mentioned compete directly with the ordinary aluminum casting alloys now in use, as typically the No. 12 alloy, with 8 per cent copper. Addition of silicon operates to increase the tensile strength above that of pure aluminum, so that with 5 per cent silicon at least 16,000 pounds per square inch may be expected, while test results will ordinarily run 17,000 to 18,000 pounds per square inch.[3] This is about 2,000 pounds less than the 8 per cent copper alloy should give. On the other hand, the elongation will be at least 3.5 per cent in 2 inches, frequently reaching 5 per cent or slightly better, as against a usual 0.5 per cent to 1.5 per cent for the 8 per cent copper alloy. Consequently the silicon alloy is far better able to withstand shocks and rough usage. Castings may be pounded or dropped on the floor without breaking and the loss from damage of this kind is likely to be considerably smaller. If off-size, they can safely be sprung slightly when forcing them to shape. Increased silicon content up to 8 per cent changes these properties very little. Typical tensile test figures for the 5 per cent and 8 per cent silicon alloys are

[3]These test results are all based on standard half-inch test rods with threaded ends.

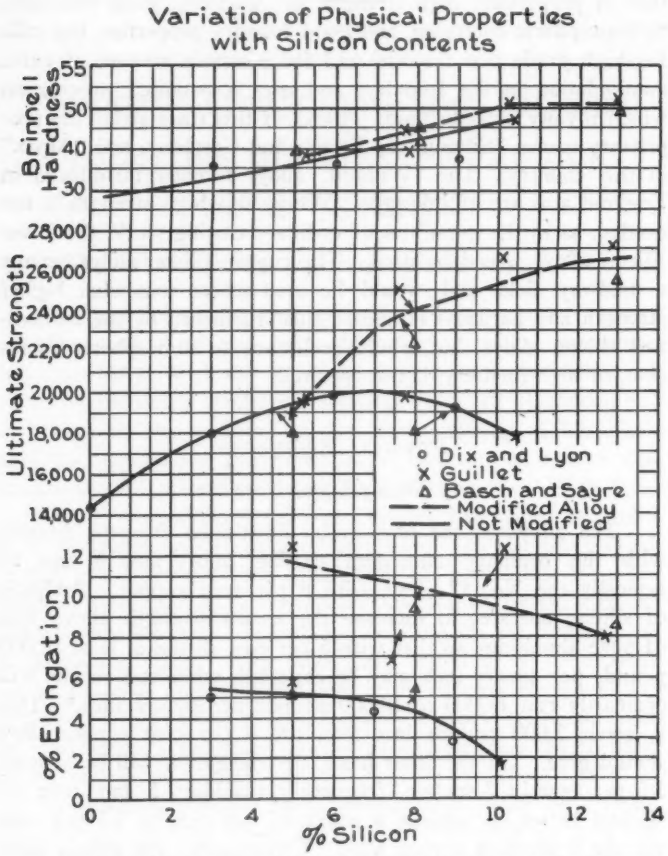

FIG. 1—VARIATION OF PHYSICAL PROPERTIES WITH SILICON CONTENT

given in Table 1, and these results coupled with others given by Dix and Lyon,[4] and with some given by Guillet[5] are plotted in Fig. 1.

Above 8 per cent silicon it becomes increasingly difficult to obtain a homogeneous structure in ordinary sand castings. The

[4]*Physical properties of some copper-silicon-aluminum alloys when sand cast.* E. H. Dix, Jr., and A. J. Lyon. Am. Soc. for Testing Materials, 1922.
[5]*Un Nouvel Alliage d' Aluminium.* Leon Guillet. Genie Civil, May 5 and 12, 1923.

Table 1

TENSILE STRENGTH
SAND CAST ALUMINUM BASE ALLOYS

Alloy	Proportional Limit	Ultimate Strength	Per cent Elong. in 2 inches	E X10⁶	Stress for permanent unit set of .00005	.0001	.0002	Brinell No.
5 per cent Si. Balance Al...	3000	17850	5.3	9.8	3700	4100	4700	40
8 per cent Si.....	3000	18000	5.5	9.7	4000	4500	5000	44
8 per cent Si. Modified....	3600	22500	9.5	10.5	4200	4700	5400	47
13 per cent Si. Modified....	6000	25500	8.5	10.8	6700	7500	8300	50
8 per cent Cu. No. 12 Alloy	6500	18000	1.0	9.0	7700	8200	9200	60-70
4 per cent Cu. 2 per cent Si.	4600	22300	2.5	10.7	5600	6500	7600	58
4 per cent Cu. 5 per cent Si.	5800	22700	2.4	9.9	7000	8000	9200	62
8 per cent Cu. 5 per cent Si.	7900	25500	1.3	10.2	10600	11700	13000	79

silicon tends to appear in large brittle needle crystals and the ductility decreases without a proportionate increase in strength. Rapid cooling in a measure prevents this action—and higher silicon content may be used in chill castings with good results.

This leads to the modified alloys. By the use of rather surprising modification methods, of which the first and most prominent one was developed by Dr. Aladar Pacz, the otherwise coarse grained high silicon sand cast alloys become improved considerably in structure, in strength, and in ductility. These processes are described in detail later on. As indicated in Table 1, this modification process increased the 8 per cent silicon alloy in strength from 18,000 pounds to 22,500 pounds and in ductility from 5 per cent to 9 per cent elongation. The 13 per cent alloy, modified, under proper foundry conditions, should give over 25,000 pounds and over 8 per cent elongation in 2 inches. This last is a better combination of properties than any of the other sand cast alloys have given. In fact, the 13 per cent silicon alloy, modified, compares with the ordinary 8 per cent copper alloy in a measure as malleable iron compares with gray cast iron.

B—Specific Gravity

Silicon is lighter in weight than aluminum, with a specific gravity of 2.4 as against 2.67 to 2.72 for ordinary commercially pure sand cast aluminum. As a result the silicon alloy castings are lighter in weight than the aluminum itself and of course materially lighter than the usual copper aluminum or zinc aluminum alloys. The 13 per cent silicon alloy will have a specific gravity of 2.60 to 2.65, with the 5 per cent alloy slightly heavier, as against

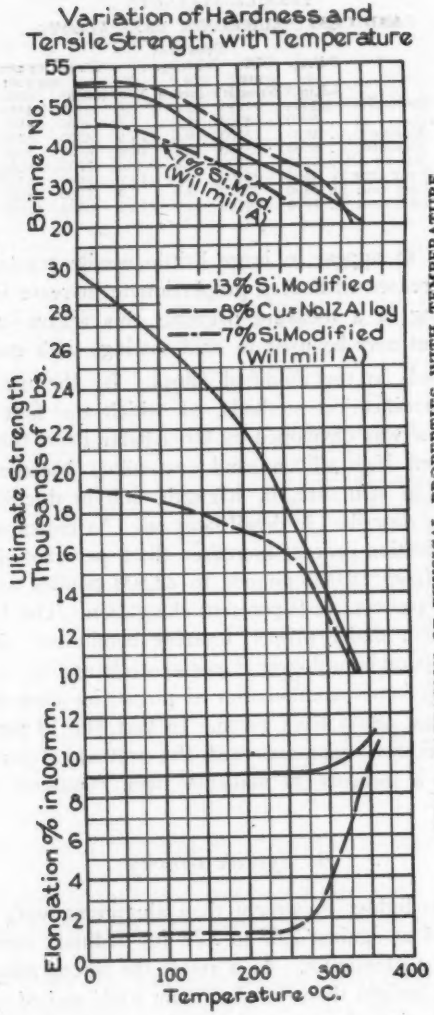

FIG. 2—VARIATION OF PHYSICAL PROPERTIES WITH TEMPERATURE

a value of 2.84 to 2.87 for the 8 per cent copper alloy. This corresponds to 0.095 pounds per cubic inch for the 13 per cent silicon alloy, .096 for the 5 per cent alloy, and to 0.103 to 0.104 for the copper alloy. Allowance should be made for this 8 to 10 per cent saving in weight when considering a change from one to the other.

C—Casting Shrinkage.

The casting shrinkage for the silicon-aluminum alloys is also appreciably less than for pure aluminum or for other aluminum alloys. Silicon itself in the solid state has only about one-third the thermal coefficient of expansion of aluminum, .0000076 per degree Cent. at 40 degrees Cent., as given by Fizeau, as compared to .0000229 for aluminum. When melting or freezing, silicon behaves like water rather than like the usual metal, i.e., it expands on freezing, so that its specific gravity is less in the solid than in the liquid state. No chemical combination exists between silicon and aluminum in the alloy, and so the alloy behaves as a simple mixture. The crystallization shrinkage (change in volume when changing from a liquid to a solid at the same temperature) as given by J. D. Edwards[6] is 6.6 per cent for 99.75 per cent Al, 5.6 per cent for the alloy containing 7.8 per cent Si, and 3.8 per cent for the alloy containing 11.6 per cent Si.

D—Pattern Shrinkage

Various figures are given for the pattern shrinkage; for the 13 per cent Si alloy; 1.25 per cent by Edwards, 1.17 by the U. S. Bureau of Mines, and 1.1 by Leon Guillet[7]. Figures given by the same three for the 8 per cent copper alloy are 1.50 per cent, 1.31 per cent and 1.25 per cent, respectively. Mean figures are 1.17 per cent or 0.14 inches per foot for the silicon alloy and 1.36 per cent or 0.163 inches per foot for the copper alloy. This smaller crystallization and pattern shrinkage in large measure explains the improved behavior of this alloy in complicated castings.

Our experience has been that castings of the aluminum silicon alloys poured from patterns made for ordinary gray iron

[6]Chem. and Met. Eng., Jan. 24, 1923, p. 165.
[7]Genie Civil, May 5 and 12, 1923.

came just about to the right dimensions, perhaps a trifle undersize, whereas, when patterns made for cast brass were used, the castings came oversize. A shrinkage rule of ⅛ inch per foot for the silicon alloys will give good results. The pattern shrinkage for No. 12 alloy (8 per cent copper) is ordinarily given as 5/32 inch per foot.

E—Resistance to Corrosion

The resistance of the silicon-aluminum alloys to corrosion in salt spray is almost equal to that of pure cast aluminum, and far better than that of the copper-aluminum alloys. Results of an extensive series of tests made by the General Electric Company on some two dozen aluminum alloys were reported at the December, 1923, meeting of the A. S. M. E.[8] These tests included the 5 per cent silicon alloy, and additional data has since been obtained on the 8 per cent and 13 per cent alloys. The 5 per cent alloy ranks best with an almost inappreciable deterioration after 8 weeks' exposure, and the other alloys are almost as good. As expected the modified alloy is not quite as good as the same alloy unmodified, but the difference is small. Silicon evidently causes practically none of the damaging effect present with such ingredients as copper and tin. These tests showed practically a straight line quantitative relation between the copper content and the rate of corrosion, reaching a 35 per cent loss of strength in eight weeks in a ½ inch diameter test bar with the 12 per cent copper alloy. German tests[9] show a similar behavior in steam, the 13 per cent silicon alloy behaving better than pure aluminum, and far better than the 8 per cent copper alloy.

Czochralski also gives figures indicating a marked improvement in resistance to nitric acid, both dilute and concentrated, but our own tests do not check this. Our figures suggested that it was more or less on a par with other common aluminum alloys in nitric and in sulphuric acids, both 10 per cent and 90 per cent concentrated. In alkaline solution (sodium hydrate) and in ammonia the 5 per cent and 13 per cent silicon alloys

[8] *Salt Spray Corrosion of Aluminum Alloys.* Basch and Sayre, Mechanical Engineering, April, 1924.

[9] *Silumin, eine Neue Leichtlegierung.* J. Czochralski. Zeits fur Metallkunde, Nov., 1921.

showed definite superiority over both commercially pure cast aluminum and the No. 12 alloy. In hydrochloric acid, as would be expected, the silicon alloys were eaten away even more rapidly than pure aluminum.

F—Leakage Resistance

One distinct advantage is the leakage resistance of these silicon alloys. They have so far been used satisfactorily under test air pressures up to 200 pounds per square inch, and with working pressures to 75 pounds per square inch, at room temperatures, even in sections relatively difficult to cast. The 13 per cent alloy, due possibly to the method of modification, usually shows in broken sections a number of extremely minute pin-holes, but these holes are so scattered that they cause no leakage.

G—Electrical Conductivity

The electrical conductivity of the modified 13 per cent silicon alloy is about 40 per cent of that of copper—as compared to 33 per cent for the 8 per cent copper alloy and around 56 per cent for commercially pure cast aluminum. The 5 per cent alloy shows a relative conductivity of 35 per cent.

H—Resistance to Shear

The shearing strength of these alloys, as measured on a ½ inch round rod in double shear, were as follows:

	Ultimate Strength Pounds per square inch
5 per cent Silicon	15,000
8 per cent Silicon, Modified	16,000
13 per cent Silicon, Modified	18,400
No. 12 Alloy (8 per cent Copper)	20,500
Cast Brass (88 Cu.-9 Sn.-3 Zn.)	34,000

These values are given in pounds per square inch of actual area in shear. We have made no tests on the true shearing

properties as measured in torsion, and have been able to find no data obtained by others.

Where possible, screw threads in aluminum castings should be avoided. The threads are soft and wear down readily if the screw is taken in and out frequently, and the screw is very likely to bind and freeze itself in place if it is at all a tight fit in the hole. In their place, through bolts should be used, or brass or other metal inserts should be placed in the casting to take the threads. Where screw threads must be used, in the silicon-aluminum alloys, an effective length of grip of one and one-half times the diameter of the screw should be furnished to develop the full strength of the screw.

H—Adaptability as Bearing Metal

Various reports have been received from Europe referring to the use of the 13 per cent modified alloy in Germany for bearings. Apparently, however, it is used as a backing metal rather than for the actual bearing itself, the load really being carried by a thin layer of babbitt or similar alloy used as a lining on the aluminum. The 13 per cent alloy is in use in this country to some small extent for actual bearings for steel shafts, but only under very light loads.

I—Machinability

When proper precautions are taken these alloys should machine as easily as other commercial aluminum alloys. The machining properties depend largely on the melting and casting practice. An alloy with an excess of iron or carbon, overheated, and allowed to oxidize shows many hard spots, and both the silicon grains and the Fe Si needles easily tear out. In view of the fact that free non-dissolved silicon will cause hard spots, and that the modification process eliminates particles of excess silicon, modification in general will tend to improve the machining qualities.

In handling aluminum silicon alloys the same precautions should be taken as with all aluminum alloys; that is, the grinding and setting of tools, as well as cutting speeds, should be adjusted to the peculiarities of the metal.

Methods Used in Redesign of Castings

To obtain full advantage of these new alloys it will ordinarily be advisable at least to check up the desirability or the necessity of making changes in the shape of the casting to make allowance for the physical properties of the new material.

Many failures have resulted, and are bound to result from changes from one alloy to another not accompanied by appropriate investigation of the suitability of the new alloy itself, and by investigation of the patterns to provide increased strength and stiffness where needed. In a great many cases no change in patterns will be needed; but a material may readily acquire a bad name through a few failures in service which could have been avoided through this precaution. This applies not simply to the silicon aluminum alloys alone, but as a general principle to the substitution of aluminum for other metals.

The dominating requirements in the design of a casting, to the extent that strength rather than foundry properties control, are ordinarily two: the permanent deformation of the casting under normal loading and particularly under such abuse as may reasonably be expected should be less than some definite amount, which in some cases may be extremely small, but in other cases may be relatively large; and the strength should be sufficiently great so that the casting will not fail in fatigue under the number of repetitions of the working loading likely to be expected during the normal life of the casting. In a brittle material, as gray iron or in some measure the No. 12 alloy, the breaking strength may be the controlling factor rather than the deformation strength. Frequently a third requirement will be introduced, that the elastic deformation of the piece under working loads shall not exceed a certain definite small amount.

To serve as a gage for allowable stresses in tension under the first requirement, unit stresses corresponding to permanent sets of one part in 20,000, one part in 10,000, and one part in 5,000, have been given in Table 1, as well as the unit stress at the proportional limit. These are rather unusual figures to give, but we have frequently found them useful, particularly as some materials with a high proportional limit will deflect rap-

Table 2

PHYSICAL PROPERTIES IN CAST FORM

Material	Specific Gravity	Wgt., Lbs. per Cu. In.	Thermal Coef. of Expansion per Degree C.	Conductivity *Thermal* Cal. per cm. per sec. per Degree C.	*Electrical* Copper = 100
Aluminum, .99 per cent pure	2.67-2.72	.097	.0000229	0.470	56
Aluminum, 5 per cent Si.	2.63-2.68	.096	.....	.....	35
Aluminum, 13 per cent Si. mod.	2.60-2.65	.095	.0000222	0.386	40
Aluminum, 8 per cent Cu.	2.84-2.87	.103-.104	.0000246	0.348	33

idly as soon as that proportional limit has been passed, whereas other materials with low proportional limits may be loaded well above this proportional limit without exceeding a relatively small set.

Ordinarily, however, the controlling factor in design will be the strength and rigidity in bending rather than in tension. Results of tests in bending are given in Table 3. These were made on bars 0.4 inch thick by 1¼ inch wide, loaded at the center of a twelve inch span. Stresses are given for the proportional limit, and for permanent deformations at the center of the span of .005 inches, .01 inches and .02 inches. The modulus of rupture is given only where break occurred before the bending had gone too far.

The strength of these alloys in fatigue, as measured in a rotating bar machine of the Farmer type, is shown in Fig. No.

Table 3

TYPICAL BEND TEST RESULTS*

Alloy	Apparent Proper. limit.	Modulus of Rupture	EX106	Stress for permanent set of .005 inches	.01 inches	.02 inches	Degrees Angle of bend at break.
5 per cent Si. Balance Al.	4700	25000	8.8	5600	6200	6900	30
8 per cent Si.	5700		11.6	7200	8000	9000	112
8 per cent Si. Modified	6700		9.6	7700	8400	9300	150
13 per cent Si. Modified	6700		12.4	7800	8500	9800	85
4 per cent Cu. 2 per cent Si.	8500	31000	8.0	10300	11200	14000	25
4 per cent Cu. 5 Si.	9000	32000	9.5	10900	11800	13300	20
8 per cent Cu. 5 per cent Si.	11000	34500	9.1	13400	17500	20300	10
8 per cent Cu.=No. 12 Alloy.	6900		8.6	8000	9000	10600	18
Gray Cast Iron	24000	48000	13.8	28000	34000	44000	1
Malleable Iron	34000		24.2	37500	44000	50000	180
Cast Brass**	10000		12.5	12000	13500	14800	180

*These tests were made on bars 0.4 inches thick by 1¼ inches wide, loaded at the center of a 12 inch span.

For a given unit stress, deflection will vary at $1^2/h$, where 1 is the length of span and h the thickness of the beam. That is, a permanent set of .01 inches, given in this table, would correspond to the same unit stress, as a permanent set of .04 inch with a span of two feet and thickness of 0.4 inch, or with a span of one foot and thickness of 0.1 inch.

**80 per cent Cu. 16 per cent Zn. 2.5 per cent Sn. 1.5 per cent Pb.

3. These tests are still going on, and the results here shown should not be taken as final. It seems to be definitely indicated, however, that the unit strength in fatigue for the alloys shown, even for as high as 50,000,000 repetitions (and few castings will reach that number of repetitions in service) is well above the proportional limit, and that there is in fact little relation between the fatigue strength and the proportional limit. The low proportional limit of these castings does not indicate a correspondingly low strength in fatigue. Except for the weakening effect from possible local flaws, castings of the moderately ductile alloys will ordinarily become useless by local deformation at loads well below the true fatigue strength. Apparently then, so far as strength is concerned, the proportional limit may safely be exceeded, provided the resultant deformation does not become objectionable. Proper safety factors of course must be introduced to allow for the large natural variations in strength of castings due to variations in composition or structure.

The following principles govern in redesign:—

(1) Where resistance to elastic deformation in bending is the governing factor, the general principle is that in proportion as modulus of elasticity decreases, the moment of inertia should be increased. When changing from cast brass, with $E = 12{,}000{,}000$ to cast aluminum alloys, with $E = 9{,}000{,}000$, the moment of inertia should be increased by 33 per cent, unless, of course, there is already excess stiffness. In case both breadth and depth are everywhere increased proportionally, an 8 per cent increase in each will suffice. In case depth only is changed, a 10 per cent increase will be needed. The full 33 per cent of course is needed in case breadth only is changed. When changing from cast iron, with $E = 14{,}000{,}000$ to aluminum, corresponding figures are 12 per cent, 16 per cent and 53 per cent. In changing from one aluminum alloy to another, no change need be made.

(2) Where the governing factor is the resistance to permanent deformation in bending under steady loads, or loads slowly applied, the section modulus must be increased in proportion as the allowable stress decreases. A fair gage of the comparative stresses for varying degrees of required stiffness

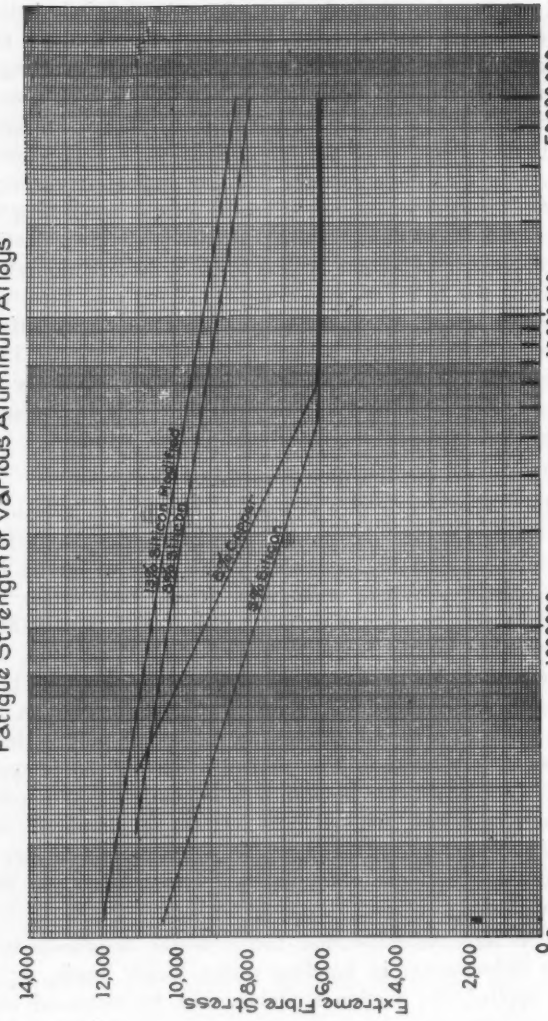

FIG. 3—FATIGUE STRENGTH OF VARIOUS ALLOYS

may be obtained from the tables already given. Safety factors depend so much upon the individual application that it is scarcely possible to give any definite figures for allowable stresses.

Roughly, where this factor controls, the allowable stresses for the 5 per cent silicon alloy should be reduced to 60 per cent and for the modified 13 per cent silicon alloy to 90 per cent of those used with the No. 12 alloy, and the section moduli should be increased by 2/3 and by 1/9 respectively. This section modulus is directly proportional to the breadth and to the square of the thickness of the section; and if the thickness can be proportionally increased throughout without changing the breadth, this increase should be 30 per cent for the 5 per cent silicon and 5 per cent for the 13 per cent silicon alloy. Putting this in other language, the unmodified silicon alloys become bent more easily and at lower loads than the No. 12 alloy. On the other hand, the silicon alloy castings can be bent back to shape, while the No. 12 alloy castings will ordinarily crack after very slight deformation. Addition of copper to the silicon alloys, while reducing ductility and resistance to atmospheric corrosion, increases this stiffness, so that indicated allowable stresses with the 8 per cent copper 5 per cent silicon alloy were materially greater than with the No. 12 alloy.

(3) More often than is generally realized, the governing factor is resistance to shock or to sudden loading, rather than to gradual loads. Ordinary abuse in handling is likely to be of this type. In this case an increase in strength is of no value except as it brings about an increase in the ability of the material to absorb energy without being deformed or ruptured. This resilience or ability to absorb energy varies with the square of the allowable unit stress, inversely with the modulus of elasticity, and directly with the volume of material involved. For any given type of loading, it may be given by the formula:

$$\text{Resilience (inch, lbs. of energy)} = \frac{S^2 V}{CE} \quad \text{when } \begin{cases} S = \text{allowable unit stress} \\ V = \text{volume, cu. inch} \\ E = \text{Modulus of elasticity} \\ C = \text{a constant} \end{cases}$$

This constant depends upon the type of loading and upon

the shape of the piece, but is independent of the material and the allowable stress.

For typical cases:

Direct tension or compression..... $C=2$

Cantilever beam of uniform rectangular cross-section:

Load at end only..... $C=18$

Load uniformly distributed..... $C=30$

Beam simply supported at ends:

Load at center only..... $C=18$

Load uniformly distributed..... $C=11.25$

Values for other cases may be found in handbooks.

The comparative ability of castings of identical size of different materials to absorb damage by a hammer blow or similar impact from without, without bending, may be roughly estimated by comparing values of S^2/E for the materials. Where the damage is done not by a blow from without but by dropping the casting itself upon the floor, a second factor enters, for the heavier casting delivers a heavier blow, and light metals like aluminum are at a distinct advantage as compared to brass or cast iron. By dividing the resilience, in inch pounds of energy per cubic inch, by the specific weight in pounds per cubic inch, the resilience may be obtained in inch lbs. per lb. and this figure measures the comparative resistance to bending from falls, of similar castings of different materials. Values for both conditions are given in Table 4. It will be noticed that the low modulus of elasticity and the low specific weight of the aluminum alloys give them a distinct advantage in the ability to ab-

Table 4

COMPARATIVE RESILIENCE OF VARIOUS ALLOYS

Alloy	Weight Lbs./cu. in. W.	EX10⁶	Comparative Resilience Per Cu. Inch S^2/E Apparent prop. limit.	Set =.010 inch	Per lb. S^2/EW Apparent prop. limit.	Set =.010 inch
5 per cent Si. Balance Al.....	.096	8.8	2.5	4.3	26	45.
8 per cent Si.....	.096	11.6	2.8	5.5	29	57
8 per cent Si. modified.....	.096	9.6	4.7	7.3	49	76
13 per cent Si. modified.....	.095	12.4	3.6	5.8	38	61
4 per cent Cu. 2 per cent Si..	.100	8.0	9.0	15.6	90	156
4 per cent Cu. 5 per cent Si..	.100	9.5	8.6	14.6	86	146
8 per cent Cu. 5 per cent Si..	.103	9.1	13.3	33.6	129	326
8 per cent Cu.=No. 12 Alloy.	.103	8.6	5.5	9.4	53	91
Gray cast iron.....	.260	13.8	41.6	83.6	160	322
Malleable iron	.264	24.2	47.6	80.0	180	303
Cast brass	.305	12.5	8.0	14.6	26	48

These values are based on the figures given in Bend Test Table—Table III.

sorb sudden blows without deforming, partly at least, counterbalancing their relatively low proportional limit.

These figures should primarily be used as comparative values rather than as absolute values; that is, the inch pounds of energy in the blow cannot be divided by the cubic inches of casting to give the inch pounds of energy per cubic inch with numerically correct results. Much of the energy of the blow is bound to be absorbed in local deformation at the point of impact, and on the other hand, inertia effects may operate to cause damage before the energy of the blow has had time to be distributed over the whole mass of the casting.

(4) The last two paragraphs apply to ability to absorb sudden blows without bending. The ability to absorb blows without cracking is a function of total resilience rather than of elastic resilience and rough comparative values can be obtained by multiplying the ultimate strength by the per cent elongation, and multiplying the result by a constant varying from 50 per cent for a very brittle material like cast iron to say 75-80 per cent for a very ductile material like the modified 13 per cent silicon aluminum alloy.

(5) Resistance to denting is measured by the Brinnell hardness. At points of local loading, as where a bolt head bears on the metal, the area of washer should if necessary be increased inversely in proportion to the Brinnell number.

Copper-Silicon Alloys

As already stated, addition of copper to the silicon alloys of aluminum operates greatly to decrease ductility while increasing the hardness and the ultimate strength. The proportional limit is also markedly increased. Resistance to atmospheric corrosion is by no means as good as with the binary silicon alloys and goes down directly with the copper content. The foundry properties of these alloys are also not quite as good.

Physical properties are shown in Fig. 4 which combines our own results with those obtained by Messrs. Dix and Lyon.[10] Some results have also been given in connection with preceding tables.

[10] *Physical Properties of Some Copper Silicon Alloys When Sand Cast.* Proc. Am. Soc. Testing Materials, 1922.

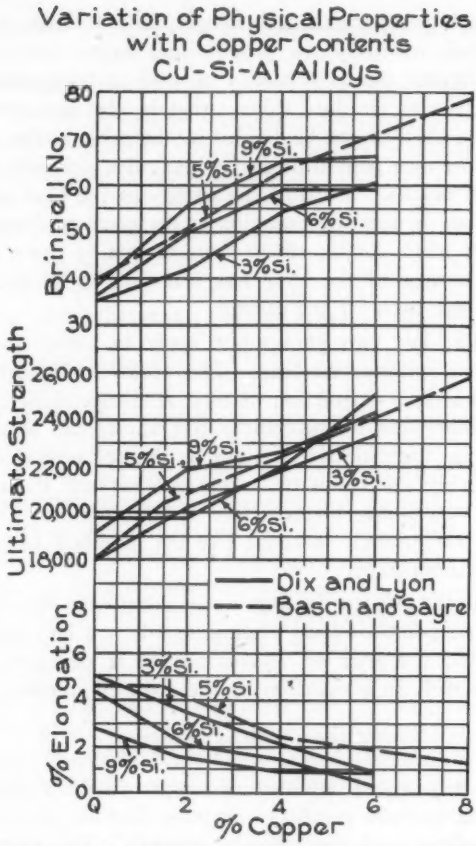

FIG. 4—VARIATION OF PHYSICAL PROPERTIES WITH COPPER CONTENT OF TERNARY Cu Si Al ALLOYS

Nothing is gained by the addition of copper to the modified aluminum-silicon alloys. The ductility seems to drop very rapidly as the copper content increases, without a corresponding increase of strength.

Foundry Treatment

The silicon aluminum alloys are ordinarily made by the addition to molten aluminum of either commercially pure silicon

or an aluminum silicon hardener. In order to maintain the permissible limits of impurities (iron, copper, etc.), and so obtain the best physical properties, only grade A aluminum with a minimum aluminum content of 99 per cent, or scrap of equivalent quality should be used, and melting containers should be employed which do not contaminate the melt with iron, such as crucibles or furnaces with non metallic linings. Melting auxiliaries such as stirrers, skimmers, ladles, etc., should preferably be made of graphite for the same reason.

Aluminum-silicon alloys in the ready mixed form, or aluminum silicon hardeners, generally with 20 per cent silicon, may be bought from aluminum manufacturers to definite specifications. The hardener dissolves readily in aluminum at a temperature not over 1300 degrees Fahr. Good clean scrap from previous aluminum-silicon melts may be used in practically all proportions dictated by production conditions. Excellent results are obtained with the unmodified alloys, when scrap from previous high silicon aluminum melts of the modified alloy can be mixed in. For instance, 40 per cent of previously modified 13 per cent aluminum silicon scrap, preheated and mixed with 60 per cent of high grade aluminum, will give an alloy nominally 5 per cent silicon with excellent physical properties (about 25 per cent higher in ultimate tensile strength and elongation than the ordinary, normal 5 per cent silicon aluminum alloy).

In making silicon-aluminum hardener, or in making the alloy itself direct from the silicon and the aluminum, additional precautions must be taken, as unless proper care is taken, the metal can easily be spoiled for the machine shop; that is, the casting will be shot through with "hard spots" which ruin the tools and prevent smooth machined surfaces.

Silicon begins to coat itself with a superficial layer of silicon oxide at about 700 degrees Fahr. in air, which is so refractory that it does not melt and run until a temperature of about 2800 degrees Fahr. is reached. It cannot be broken up by the molten aluminum during the alloying process and is distinctly discernible in the cast metal. There are other elements which may cause hard spots, such as excess, non-dissolved silicon, iron silicides and silicon carbides, as brought out more in detail in another part of this article, but hard spots caused by faulty mix-

ing and melting routine are ordinarily much more prevalent than those caused by other factors. When metallic silicon is added directly to molten aluminum, care should therefore be taken to push it without delay below the surface of the melt, so that it will coat itself immediately with molten aluminum and thereby prevent air oxidation. It should not be allowed to remain on the surface exposed to air or flame for any length of time before it is pushed under. For the same reason the silicon should be used only in the form of clean lumps of appreciable size (½ to 1½ inch), which can be seen and followed distinctly; no screenings or dust should be permitted to enter the mix, as, on account of their minute size, they can not very easily be distinguished from surface scum or pushed below the level.

The temperature of the melt when adding the silicon should be at least 1400 degrees Fahr., but need not rise much above this. Although the melting point of silicon is very high, there is no need of approaching this figure and so endangering the aluminum by excessive oxidation, as pure silicon is readily absorbed by aluminum if the temperature of the latter is not less than 1400 degrees Fahr.

Before adding the silicon, the melter should satisfy himself that it is clean and pure, and free from oxide films, which might be due to faulty methods in manufacture. Silicon should be cast by the refiner in molds in which the top or exposed surface is reduced to a minimum so that it can be knocked off and thrown away without too much loss. Since silicon can be produced with such low iron content (1 per cent max.) the necessity for casting the silicon on shallow molds to prevent segregation no longer exists and it is commercially possible to scrap that part of the melt which may have been oxidized, that is, the surface exposed to the air. Pure, refined silicon has a bright bluish gray metallic lustre. The superficial oxide coating which causes trouble is a dull dark gray. This oxide, however, should not be confounded with the light gray particles which sometimes may be noted on a piece. These particles are detachable and are little pieces of slag. They do not cause much trouble in the alloy, as they will generally rise to the surface as dross.

The foregoing statements apply both to the modified and to the unmodified aluminum-silicon alloys, alloys up to 8 per

cent in silicon being generally unmodified, and 8 to 13 per cent generally modified. The unmodified alloy, after mixing, as already described, is cooled if necessary to proper pouring temperature, and poured just as with the commonly used aluminum casting alloys, using similar precautions. The modified alloy calls for a special modification process while in the molten state after mixing and before pouring, and for certain additional precautions, as to material used. This modified material tends to revert when liquified, and the process must be repeated each time the material is remelted.

The modification process in its theoretical aspects is explained in another part of this article. Here we shall consider only the practical application of the most commonly used method, that originated by Dr. Aladar Pacz.

This consists of mixing with the molten silicon-aluminum alloy a special modifying powder of patented composition, containing essentially an alkaline fluoride. The chemical reaction of the modifying agent on the melt requires a minimum temperature of about 910 degrees Cent. Too high a temperature will cause premature loss of the active element. The mechanism of modification is therefore broadly as follows:

The melt is brought up gradually to about 960 degrees Cent. The heat is then shut off and when pyrometer readings show that the temperature of the melt is falling and around 950 degrees Cent. the pot is skimmed and about 3 per cent (by weight) modifying powder is thrown on the surface of the melt. The pot is next covered with an asbestos sheet to prevent surface radiation of heat and enough time is allowed to let the powder become properly fused (this may take from 3 to 5 minutes). The powder is then stirred in thoroughly, with particular attention to the rim and edges, so that no powder adheres to the walls and the metal is left to cool down to the required pouring temperature.

With these alloys, on account of the higher silicon contents, it is even more important than with the unmodified alloys that the iron and other impurities be kept at as low a figure as possible. The higher the silicon, the lower the permissible amount of iron; where, for instance, a 5 per cent silicon aluminum alloy may contain as much as 1 per cent iron in the casting

without lowering the physical properties, a 13 per cent silicon aluminum alloy should have no more than 0.6 per cent iron.

Important Considerations for the Foundryman

From the foundryman's standpoint the following specific points are especially important:

1. In the whole refining or modification process the outstanding requirement is a temperature of not less than say 915 degrees Cent. when the actual final chemical reaction between the powder and the melt takes place, that is, after the powder has been stirred in. All steps previous to the stirring in should be so timed that pyrometer readings, skimming, throwing on of powder, letting it fuse to the proper consistency, and stirring in, will not let the metal cool below 915 degrees Cent. On the other hand, at the high temperatures necessary for the process aluminum is particularly susceptible to absorption of air and gases, showing in the casting as small pinholes. Furthermore, at temperatures much above the reaction point the useful components of the refining powder burn out too quickly without performing their proper function, therefore the lower the temperature to which the metal must be heated to provide a safe starting point for the whole procedure, the more solid the casting will be and the more benefit will be derived from the amount of modifying powder employed. For obvious reasons stirring, especially at the high temperatures, should not be done violently, so as to avoid beating in air. Stirring can not be done away with entirely, but it should never even approach churning.

2. The effect of modification wears off gradually while the metal stands in molten condition after the completion of the chemical reaction and the metal reverts to the unmodified condition. Not more than 10-12 minutes should be allowed to elapse between the finish of the modification and the pouring. The best pouring temperature is around 720 degrees Cent.; temperatures much above 730 degrees Cent. are objectionable.

To cut down the time required for the metal to cool from the refining temperature to the pouring temperature, from 15 to 20 per cent of previously refined gates and sprues, preheated to between 300 and 400 degrees Cent., may be added to the melt right after the powder has been stirred in. No extra modify-

ing powder need be added for this lot of metal, so that with this practice the amount and cost of modifying agent is cut down, the oxidation losses of the total melt during the high temperature periods are reduced and loss of the modification effect due to prolonged standing in the molten condition is prevented.

3. Exact determination of the temperature of the melt is very important. Quick reading pyrometers frequently checked should be used. Readings should be taken when temperature is falling so as to eliminate the effect of the hot crucible. A simple and reliable check of temperature conditions before modification can be obtained by throwing small quantities of refining powder on the surface of the melt from time to time before actually starting the modification process. If the powder on striking the surface immediately bursts into yellow flame, the melt is too hot. If the powder even when poked and stirred with a rod does not show any yellow flame, the melt is too cold; the temperature is just right if yellow flames shoot up from the powder when it is poked. If the melt has been allowed to cool down below the proper temperature, the metal may be heated up to the required value again without endangering the results.

4. The fluoride component of the modifying powder has a great affinity for the silica, which is in all plumbago crucibles, so that the life of such crucibles, if modification is carried on in them, is materially reduced by the modification process, unless they are protected by special protective coatings or washes. Crucibles should be carefully cleaned and scraped at the end of each day.

5. There is no definitely established practice as to the maximum amount of metal which may be modified at a time.

In Germany they use either 80 kilograms graphite crucibles and refine in the ladle or 48 kilogram crucibles and refine in the pot. In France they use 48 kilogram crucibles for melting and refining. In England they refine as much as 600 pounds at a time in an iron ladle lined with clay and graphite. In this country the metal, as far as can be ascertained, is generally modified in crucibles holding from 60 to 120 pounds. Where large castings have to be poured, requiring more metal than one

crucible can produce, it seems to be universal practice to refine in a battery of crucibles simultaneously and to pour from as many crucibles as required, taking care that the pouring temperature in all crucibles is as nearly equal as careful pyrometer readings can establish.

Best results will be obtained if the amount of metal modified in one crucible is kept as low as possible, as thereby the best diffusion of the modifying agent throughout the melt can be brought about.

The practice of melting and heating all metal to the proper refining temperature in a common large furnace and filling the refining crucibles from this furnace before modification has some attractive features from a production standpoint, but the extra step of pouring the metal at 950 or 960 degrees Cent. from furnace into crucible even when done very carefully is bound to introduce air into the melt.

6. The effect of modification disappears largely on remelting. Modified metal, when remelted, will revert practically to "normal" metal again, with only a little better properties than unmodified alloys of the same composition.

Gates, sprues and other scrap from previously modified heats must be remodified when remelted. However, some effect of the previous modification remains in the metal, even when remelted, and a mix containing some previously refined scrap in addition to new metal will generally produce metal with higher physical properties than a mix of all virgin metal. If 100 per cent previously refined scrap could be used in a melt, the results would be thoroughly satisfactory. The actual percentage of scrap and virgin metal will naturally depend on production conditions.

7. If previously refined scrap is used with virgin metal, cognizance must be taken of the fact that some aluminum burns out in every melt and that, unless some extra aluminum is added from time to time to make up for these melting losses, the mix is apt to get too rich in silicon. The actual amount to be added will naturally vary with the per cent of scrap used and with melting conditions. It will ordinarily be between 1/4 and 1/2 per cent per heat.

Periodical analyses of the cast metal for silicon and aluminum will be very helpful to establish the exact amount of aluminum additions required to maintain the desired composition.

There are numerous variations of the routine outlined above. In France, for instance, 2 crucibles are employed. The metal is heated in one, while the other crucible is preheated to a cherry red and has the modifying powder placed in it. When the metal is hot enough for modification, it is poured in the second preheated crucible over the modifying powder. No stirring is necessary and the metal is cooled down to proper pouring temperature, within a short time. The French claim to obtain good results from this practice.

Other modification processes have been used in this country, such as those employing metallic sodium of bismuth and antimony or other reagents. However the Pacz process as described seems at the present time the only one used on a broad scale.

Dr. Pacz recommends in addition to the modification process the use of his so-called super-refining powder, which contains manganese mixed in various proportions with aluminum. He claims that manganese (to about 1/2 per cent of the total weight) has a very beneficial effect on the grain size of the high silicon alloys and that especially in heavy sections the use of the super-refiner insures uniformity of structure. The powder as put up by the inventor requires high temperature for melting and it should therefore be added just before the modification process proper is started. The effect of the super-refiner does not wear off—as does the modification effect—and in remelts it is therefore necessary only to add super-refining powder for the new, not previously super-refined, metal.

From our experience there seems to be considerable evidence that the super-refining powder actually does benefit the structure. Whether the additional expense and complication is justified by the results, is a matter which should be decided by every foundryman individually.

Molding Practice

Molding methods are about the same as with the No. 12 alloy, but the fluidity of the silicon alloys and their freedom from hot shortness is such that if anything fewer precautions are needed.

Several small gates to the casting are preferable to one large gate, if thereby the path to be traversed by the molten metal can be shortened. This is true especially with the modified alloy, which is practically an eutectic, and therefore has a very small freezing range. Skim gates should be cut in ahead of each entrance to the casting proper. Extra heavy sections of modified metal which are apt to stay hot for an undulŷ long time, should be chilled so as to preclude the possibility of partial reversion. This metal also flows so freely that it is more likely to trap air in the mold than more viscous alloys and allowance for this should be made when venting the mold.

The question of pattern shrinkage has already been taken up in a preceding section (see page 7). A shrinkage rule of ⅛ inch per foot has given good results with these silicon alloys.

Effect of Impurities

The required physical and chemical properties of the alloy depend on the maintenance of certain limits in composition. Iron is the greatest obstacle to the realization of a perfect alloy. Iron if present as impurity combines both with the aluminum and silicon, forming definite compounds corresponding to the formulæ $FeAl_3$ and FeSi. The $FeAl_3$ will in turn form an eutectic with aluminum closely approximating pure aluminum. The FeSi separates primarily as a contaminating constituent of the finished alloy. The iron silicide appears as a coarse needle-like constituent in the micro structure. The modification has little if any refining effect upon the size and distribution of the iron silicide grains so that the presence of the latter results in abrupt loss of ductility. Large amounts of iron not only jeopardize the physical properties, but they also affect disadvantageously the corrosion resistance. The amount of iron which the alloy can contain without undue effect varies with the amount of silicon. The more silicon, the less iron should

be in the mixture. Where a 5 per cent silicon alloy in the casting may contain as much as 1 per cent iron, the 13 per cent alloy should not contain more than 0.6 per cent.

Copper forms compounds with both aluminum and silicon. The addition of copper strengthens the unmodified alloy at the expense of ductility, but causes no improvement when used in an alloy obtained by the modified process. On the contrary, it is believed that in the modified type, the best combination of strength and ductility is obtained in the absence of copper. The addition of copper also reduces the resistance to atmospheric corrosion. Copper is sometimes added to the unmodified alloy intentionally in percentages ranging from 2 to 8 per cent, but the copper contents in the modified alloy should never be in excess of 0.8 per cent.

In some commercial grades of silicon there is a considerable quantity of carbon chemically combined with the silicon to form silicon carbide. The silicon carbide, like the iron silicide, is a coarse crystalline constituent, which is insoluble in liquid aluminum. It forms no eutectic mixture with it, is not refinable by the modification process, and exists in the finished alloy in the form of hard spots. It is very important that the silicon employed in the mixing of the alloy contain a minimum amount of carbon.

In order to safeguard the properties of the alloy, as dependent on the chemical composition, the very purest grade of silicon should be used in all cases. Silicon is now marketed which contains a minimum of 97 per cent silicon with a maximum of 1 per cent iron, the remainder being mostly aluminum.[11] If a silicon aluminum hardener is used, it should be at least proportionally pure.

Zinc may be present in the alloy in moderate quantities, such as may be added in the use of zinc chloride as a flux, not exceeding 0.2 to 0.25 per cent. No advantage can be obtained, at least in the modified alloys, by the use of a flux, and in these there is therefore no reason for having any zinc at all.

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[11]With higher percentages of iron the danger of segregation increases, and unless special means are adopted to prevent such segregation, a considerable difference in the iron contents of silicon lumps taken from one shipment may result, which in turn may have serious effect on the desired composition of single castings. If, on the other hand, the refiner of the silicon metal adopts measures to prevent segregation, such as pouring in shallow molds, heavy surface oxidation may result, which causes bad hard spots.

Theory

A glance at the silicon aluminum equilibrium diagram will help in understanding the properties of these alloys. Pure aluminum melts at 658 degrees Cent. and pure silicon at 1,420 degrees Cent. Apparently no chemical compounds between the two exist. On the aluminum side of the diagram, silicon is soluble in aluminum, forming a solid solution whose limits are not very definitely established, lying somewhere between 0.7 and 1.5 per cent silicon. A similar solid solution may form on the silicon side of the diagram, but there is very little evidence concerning it. If it forms at all, it will contain but little aluminum. The silicon and the aluminum, or the two solid solutions, combine to form an eutectic with about 13 per cent silicon, melting at 570 degrees Cent.[12]

Explanation of Plates

A photomicrograph of a 5 per cent silicon-aluminum alloy, unmodified, is shown in plate 1. The silicon is present in long needle-like crystals, which in the main group themselves around the grains of aluminum, or rather the grains of aluminum-silicon solid solution. This photomicrograph and the following ones,

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[12]There are two different theories as to the eutectic, which do not agree very well. Zay Jeffries and J. D. Edwards (1)* state that the aluminum silicon alloy can appear in two different forms. The one, the so-called normal form, with a coarse grained structure, is obtained when the aluminum and silicon are simply melted together. The second form, which Jeffries calls "modified," with a fine grained structure, was obtained in 1911 by Frilley by means of the simultaneous electrolysis of alumina and silica, but the great technical significance of the process failed to be recognized.

For the first or "normal" alloy, the eutectic was found to contain 11 to 12 per cent silicon, and to have a melting point of 577 degrees Cent., while the alloys prepared by electrolytic reduction had a eutectic composition of 15 per cent silicon with a freezing point of 564 degrees Cent.

The modification method developed by Dr. Pacz was explained by Dr. Jeffries as operating to throw the metal from the first into the second type above mentioned, and so to give a much finer grain with a higher eutectic composition than otherwise.

This theory as to the existence of two eutectics in the Al-Si system is not shared by Leon Guillet (2) and by the German investigators such as Meissner (3), Czochralski (4), Welter (5), and Rassow (6), who consider that only one eutectic composition can exist. Both Rassow and Welter in particular give figures which place this eutectic at 13.8 per cent Silicon.

(1) *Aluminum Silicon Alloys.* Zay Jeffries. Chem. and Met. Eng. Vol. 26, p. 750. Apr. 19, 1922.
Thermal Properties of Aluminum Silicon Alloys. Junius D. Edwards, Chem. and Met. Eng. Vol. 28, p. 165, Jan. 24, 1923.
(2) Revue de Metallurgie. May, 1923., p. 303.
Genie Civil, May 5 and 12, 1923.
(3) Zeitschrift für Metallkunde, Jan., 1923, p. 17.
(4) Zeitschrift für Metallkunde, Mar., 1923, p. 78.
(5) Zeitschrift für Metallkunde, April, 1923, p. 107.
(6) Zeitschrift für Metallkunde, April, 1923, p. 106.

*The small numerals in parentheses refer to the number of the bibliographical references given at the end of footnote 12.

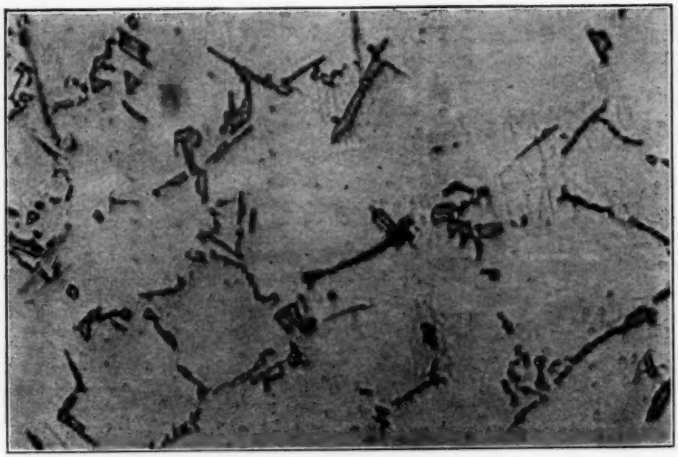

PLATE 1—PHOTOMICROGRAPH, 5 PER CENT Si ALLOY

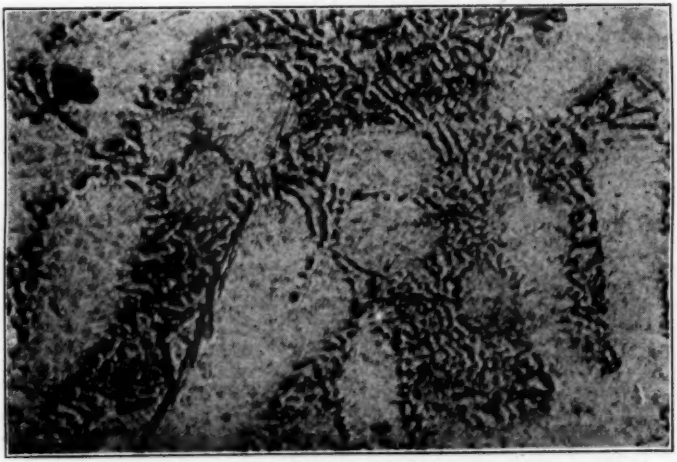

PLATE 2—PHOTOMICROGRAPH, 8 PER CENT Si ALLOY

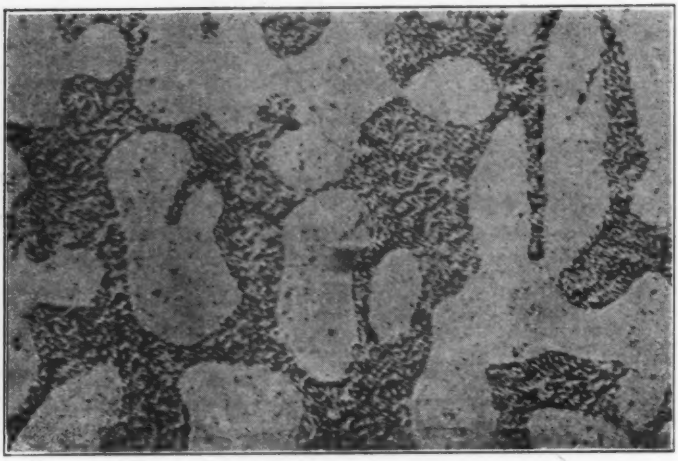

PLATE 3—PHOTOMICROGRAPH, 8 PER CENT Si ALLOY, MODIFIED

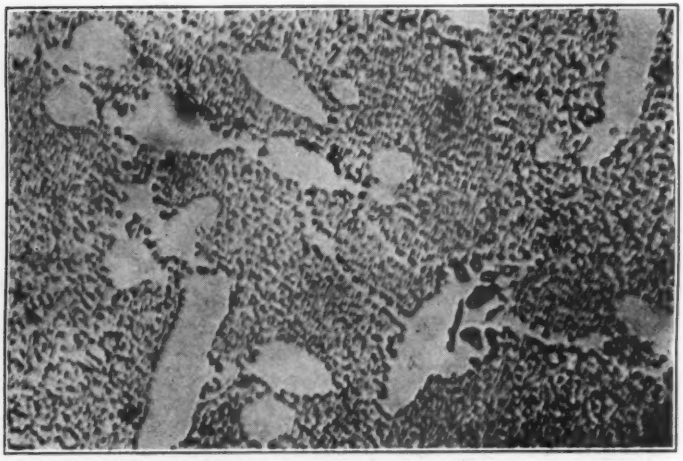

PLATE 4—PHOTOMICROGRAPH, 13 PER CENT Si ALLOY, PROPERLY MODIFIED

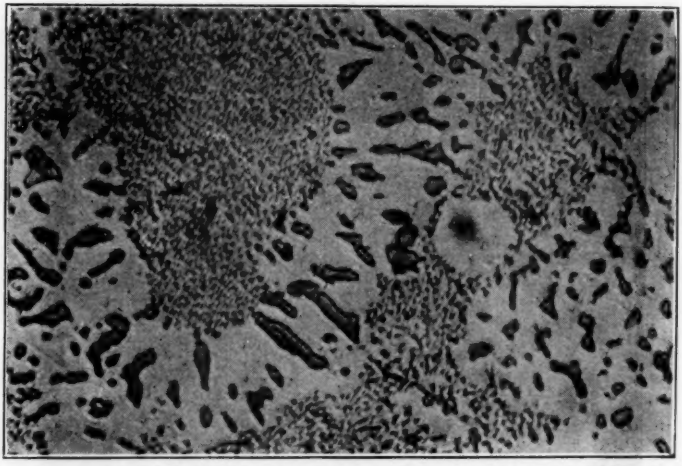

PLATE 5—PHOTOMICROGRAPH, 13 PER CENT Si ALLOY, IMPERFECTLY MODIFIED

except No. 6, are all to 200 diameters magnification, and unetched, or only etched sufficiently to bring out more clearly structure already visible before etching. Plate 2 shows an unmodified 8 per cent silicon aluminum alloy, with grains of aluminum surrounded by the relatively coarse grained silicon-aluminum eutectic. The improvement in grain size of the eutectic due to modification shows up in plate 3, which is a modified alloy of the same composition. Plate 4 is a modified alloy of approximately 12 per cent Si, somewhat below the eutectic. Two or three unabsorbed silicon crystals appear in one of the grains of aluminum, but otherwise the silicon is all present in the fine grained silicon aluminum eutectic. Plate 5 shows an imperfectly modified 12 to 13 per cent silicon alloy. These were all taken from tensile test bar samples, and the corresponding tensile test figures are given in table No. 5. Plate 6 shows 13 per cent silicon alloy, properly modified, but with excess iron content. This is to 75 diameters magnification. The long narrow crystals of iron silicide are very characteristic. A 4 per cent Cu.-5 per cent Si alloy, to 200 diameters, is shown in plate 7.

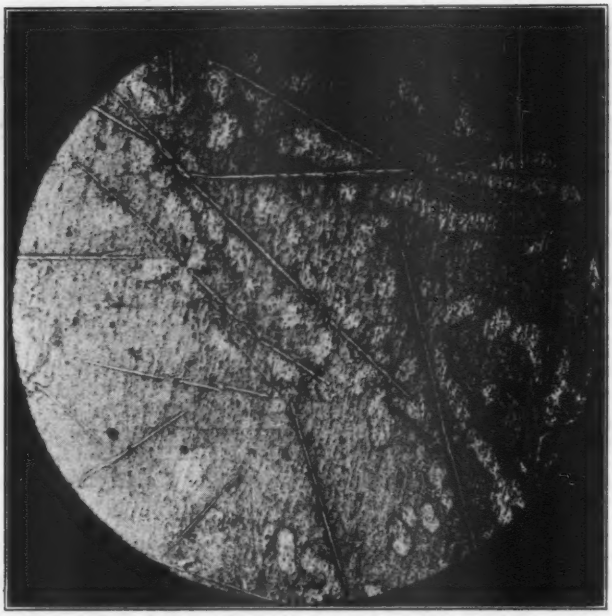

PLATE 6—PHOTOMICROGRAPH, 13 PER CENT Si ALLOY, PROPERLY MODIFIED, BUT WITH EXCESS IRON (1.4 PER CENT Fe)

For convenience in gaging the type of the alloy by the appearance of the fracture, an attempt has been made in plate 8 to show the appearance of the fractured ends of these test bars to double full scale, but this is a difficult task to accomplish satisfactorily.

Table 5

TENSION TEST RESULTS FROM THE TEST BARS SHOWN IN PHOTOMICROGRAPHS

Plate	Alloy	Propor. Limit	Ult. Stren.	Per Cent Elong. in 2 Inches	E	Stress for Permanent Unit Set of .00005	.0001	.0002	Brinnell No.
1	5 per cent Si. Bal Al.	3000	18100	4.0	9.2	4100	4600	5200	40
2	8 per cent Si.....	3000	17700	5.1	10.0	4100	4600	5050	44
3	8 per cent Si. modified	3000	25700	13.5	11.6	3800	4200	4950	53.5
	13 per cent Si. modified.								
4	Good sample.....	4500	27000	11.0		6300	7700	9000	53.5
5	Poor sample.....	3500	21500	7.5	12.2	3850	4300	6000	47.5
4	Good sample.....	4500	27000	11.0		6300	7700	9000	53.5
5	Poor sample.....	3500	21500	7.5	12.2	3850	4300	6000	47.5

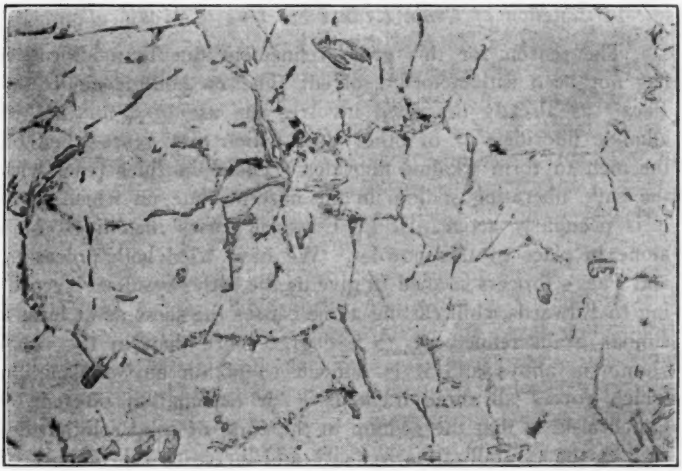

PLATE 7—PHOTOMICROGRAPH, 4 PER CENT Cu, 5 PER CENT Si ALLOY

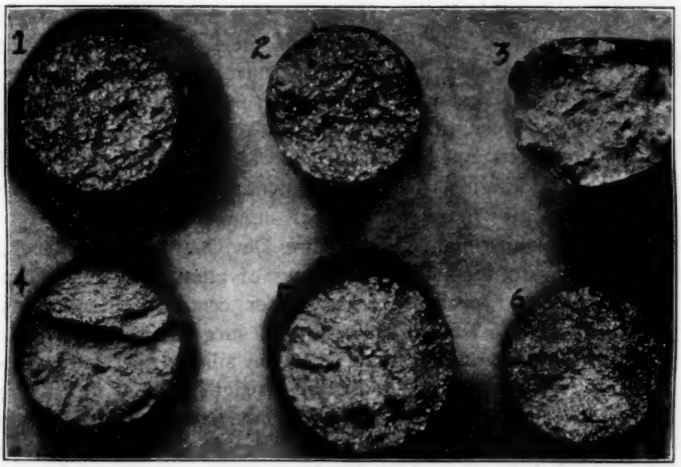

PLATE 8—TEST BAR FRACTURES CORRESPONDING TO PHOTOMICROGRAPHS OF PLATES, BAR NO. 1, PLATE 1; BAR 2, PLATE 2; BAR 3, PLATE 3; BAR 4, PLATE 4; BAR 5, PLATE 5; BAR 6, PLATE 7

Discussion of Grain Refinement Due to Modification

The reason for this grain refinement due to modification has not been satisfactorily solved. The method developed by Pacz[13] as already described involves the use of a mixture of alkaline fluorides, or of other salts which may react when on the melt to form alkaline fluorides. These fluorides react with the bath, liberating sodium in the nascent state, in which form it is peculiarly active. J. D. Edwards[14] uses metallic sodium alone in place of this powder. We have tried both processes, and Pacz's process seemed to give us the better results. According to Edwards, chill casting alone causes the same or at least a similar grain refinement, to a degree more than in the usual aluminum alloy; and it is difficult to obtain any explanation which covers all three methods. An explanation offered by Czochralski is that the sodium in the form of solid solution decreases the crystallization velocity and increases the number of crystallization cores, and so greatly increases the dispersion of the silicon. Guillet bases his explanation on a cleaning action of the sodium, rendering the silicon more easily soluble in the aluminum; but this does not seem to explain the reversion of the alloy on remelting, nor does it explain the fact that the fluorides do not have the same cleaning effect on other aluminum alloys.

The silicon aluminum alloys represent a rediscovery rather than a new development. The history of these alloys has been recently covered by Jeffries, in his article in Chemical and Metallurgical Engineering, already mentioned, and it is scarcely necessary to give more than a brief summary here.

Both Wohler and H. St. Claire Deville, working independently, prior to 1856, prepared alloys of aluminum and silicon which contained probably over 10 per cent silicon. Adolph Minet, in 1890 to 1895, made tests on a large number of aluminum silicon alloys, and found that the silicon operated materially to increase both hardness and strength without destroying the ductility. Guillet, in 1906, recommended the use of silicon alloys, up to 10 per cent silicon, for mechanical purposes on account of their strength and lightness.

[13]Patents: U. S., No. 1387900, Aug. 16, 1921; France, No. ....., Aug. 30, 1920; France, No. 523665, Aug. 22, 1921; England, No. 160426, March 18, 1921.
[14]U. S. Patent No. 1410461, March 21, 1922.

Despite this, the impression became almost universally prevalent that silicon was a harmful impurity in aluminum, as harmful as iron, and every effort was made to keep down the amount to a minimum. This may have been due in part to unfortunate experiences with alloys with high silicon content, over 10 per cent, which when unmodified give a very coarse crystalline fracture and low tensile strength and elongation, and in part to unsuccessful results with lower silicon contents, where impure silicon or high iron content aluminum ingot had been used.

As a result, very little had been done in the way of actual use of the silicon alloys until 1921, when in connection with some research work on aluminum alloys for naval applications, the General Electric Company, out of a long series of various alloys developed by different manufacturers, selected the 5 per cent silicon alloy as the one combining to the largest extent the properties required from an all around useful alloy, and adopted it for broad use. The use of the alloy from that date on seemed to increase by leaps and bounds, not only in the General Electric Company, but throughout the country.

Somewhat prior to that time Aladar Pacz of Cleveland, Ohio, had developed the "modified" alloy, taking out his first patent in 1920, and full credit must be given to him for this valuable discovery. The modified alloy has been used to a very considerable extent for several years in Germany, France and England, but in this country their use is just getting under way. Its adoption by the United States Navy as a standard alloy is bound to result in its widespread application.

Discussion—Foundry Treatment and Physical Properties of Silicon-Aluminum Sand Castings

By Jerome Strauss, Philadelphia, Pa.

The author's paper presents a more comprehensive summary of the preparation and characteristics of these commercially-new casting metals than has thus far appeared in the technical press. This dissemination of both design and manufacturing data promises more extensive application of the alloys than could result from their utilization by any manufacturing or consuming institution, for the technical public is more and more learning to distinguish exploitation based upon sound technical foundations from that which is salesmanship alone.

Numerous experiments by the writer with the 5 per cent silicon alloy have confirmed the authors' conclusions on the effect upon machinability (applying the term in the combined sense of ability to yield smooth machined surfaces and as a measure of tool abrasion) of the process of modification. The presence or absence, however, of foreign substances introduced by thoughtless methods of hardener preparation, as discussed in detail in the paper, may readily have a greater influence upon machinability than the form and distribution of the excess silicon. A great proportion of defects of this character are lost in the remelting of the alloy and therefore occur to a much less degree in castings prepared from 100 per cent scrap charges of this composition.

The tensile properties reported by Messrs. Basch and Sayre for the modified 13 per cent silicon alloy are distinctly superior to those which have been claimed by others and to many that have been found by the writer on coupons and castings from several different sources. It would be interesting to learn, in the light of the very careful foundry procedure outlined in such detail, the actual extent to which each feature contributes to

the final result, in order that these dissenting opinions (and results) might be better understood.

In considering these ductile alloys of aluminum and there are not many that can claim this distinction, it would be well to direct attention to a series of aluminum-copper-manganese combinations previously described by McKinney[1]. The one which has been generally adopted for sand castings has an average composition of 1.2 per cent copper and 0.9 per cent manganese with iron about 0.5 per cent and silicon 0.3 per cent. This combination is produced to specification requirements of 18,000 pounds per square inch tensile strength and 8 per cent elongation in 2 inches on a *machined* test piece; actual tests average about 20,000 pounds per square inch with 10 per cent elongation and frequent tests as high as 21,500 pounds per square inch and 14 per cent. The proportional limit varies between 3,000 and 4,000 pounds per square inch. The authors have considered ability to resist impact stresses on the basis of elastic resilience and "total resilience." The relation of the latter value to actual service behavior cannot be said to be any better known than the same relation for notched-bar impact tests and hence these may be employed with equal assurance as a measure of ability to resist rupture under sudden stress application. By the authors' method of comparison the Cu-Mn alloy would be superior to the 5 per cent silicon alloy not only because of increased strength and ductility but because of the larger multiplying factor resulting from higher ductility. In notched-bar impact tests the Cu-Mn alloy is actually superior with Izod values of 6 to 10 foot pounds contrasted with 3 to 5 foot pounds for the 5 per cent silicon alloy.

In corrosion tests made with a sea-water spray and in actual exposure to sea-water and sea-air in service, it has not been found to date that any differences exist between these two alloys. The Cu-Mn alloy does, however, have a satisfactory record of long service under mild conditions of exposure. It can, moreover, be readily hand-forged or drop-forged, giving a tensile strength of over 22,000 pounds per square inch and 20 per cent elongation in 2 inches.

[1]P. E. McKinney, *Aluminum Castings and Forgings* Trans. American Institute of Metals, 1916, p. 166.

Much comment has at times been made in respect to the high total contraction and hot-shortness of aluminum alloys containing manganese, resulting in large foundry losses due to cracked castings and large risers. This is very true with the 1½ per cent manganese alloy but does not well describe the behavior of this Cu-Mn combination. This may well be illustrated by data on the manufacture of a rectangular box with five solid sides ¼ inch thick and open at the top, outside dimensions 13x22x28½ inches with numerous irregular bosses up to 1x3x3 inches on the interior. The boxes were cast with no supporting ribs and only two thin tie rods across the open side; after a careful study based upon results from the first heat of castings, the total loss amounted to 3 per cent. It is not contended that physical characteristics during and just after solidification are as good as those of the 5 per cent silicon composition or that the metal is as fool-proof but it is capable of producing equally as good or better castings in the hands of experienced foundry personnel. It possesses a most desirable combination of properties.

The low-silicon alloys have had and still enjoy a widening sphere of utilization which they well merit. Equal success with the high-silicon modified combinations will depend in a great measure upon methods employed in the administration of the patent rights involved.

AUTHOR'S REPLY:

When any foundry is unable to obtain the physical properties specified for 13 per cent silicon-aluminum alloy it is in practically every case due to the fact that they did not start out with a sufficiently pure material.

A 13 per cent silicon alloy must have a very low iron and copper content and any excess of these two constituents will immediately show reduced physical properties, particularly in ductility. We were not able to obtain the specified properties until we had established the most vigorous system to check the analysis of the raw materials.

The next important point is the maintenance of the proper refining temperature and avoidance of too long periods between

the modification and puring. The mechanism of modification itself is not very difficult and if once mastered will give very little trouble.

Regarding Mr. McKinney's aluminum-copper-manganese alloys: The combination of 0.9 per cent manganese, 1.2 per cent copper referred to in this discussion, is of course quite superior to the original form of Mr. McKinney's alloy with 2 per cent manganese and 1 per cent copper. Its properties are undoubtedly somewhat better than the 5 per cent silicon alloy, but not as good as the 13 per cent silicon alloy and as long as the main requirement of the navy is to reduce weight rather than cost, the principal reliance for navy application will have to be placed in the 13 per cent silicon alloy.

For other commercial work where the reduction of weight is not so important, and there is undoubtedly a great deal of it, the McKinney alloy should show up very well, especially where somewhat higher properties than the 5 per cent silicon alloy are needed and where the modification process would entail unnecessary complicatio.

Discussion—Foundry Treatment and Physical Properties of Silicon-Aluminum Sand Castings

By R. S. Archer, Cleveland, Ohio

The use of the aluminum-silicon alloys, long known but neglected, has had a marked development during the last four or five years. The revival of interest in these alloys is due to the remarkable discoveries of Aladar Pacz in regard to the possibilities of the refining or modifying process. The attention thus concentrated on the alloys has led to an appreciation of the utility of some of the alloys in the normal or unmodified condition, but even in considering this phase of the development, full credit must be given to the pioneer work of Pacz. In view of the implication in the paper by Basch and Sayre to the effect

that the use of the 5 per cent silicon alloy dates from the investigations of the General Electric company, it may be mentioned that this alloy had a considerable commercial use prior to and independently of the investigations referred to.

Both the users and manufacturers of aluminum castings are indebted to the authors of this paper for their detailed and painstaking study of the aluminum-silicon alloys. The variety of topics which they have investigated shows that they have considered the subject from many angles, both practical and theoretical. It is only natural, however, in view of this variety of topics and the comparative newness of the alloys that there should be some points upon which other investigators do not agree entirely with the authors. Aluminum-silicon alloys have been studied very extensively by the research bureau of the Aluminum Company of America, and it may be of interest to bring out some of the facts and opinions developed in the course of this work.

Messrs. Basch and Sayre state that the alloys containing 8 to 15 per cent silicon must be modified to be of value. Any statement made at the present time regarding the value of these alloys is perhaps largely a matter of opinion. It seems quite likely, however, that some of the alloys in this range of composition may be of very considerable value even without modification. As stated by the authors of the paper, the aluminum-silicon alloys owe their value largely to their good foundry properties as well as to their physical properties. An alloy containing 10 per cent silicon possesses these good foundry properties whether or not it is modified. Furthermore, the physical properties are by no means to be despised since a tensile strength of about 20,000 pounds per square inch with an elongation of about 3 per cent may be obtained. If the modification process is not used it is not desirable to make sand castings containing more than about 11 per cent silicon. The modifying process makes it possible to use a higher silicon content.

The authors point out that the alloys of aluminum with silicon and copper are inferior to the pure aluminum-silicon alloys in respect to resistance to atmospheric and salt water corrosion. The terms in which this fact is presented may lead to an exaggerated idea of the corrodibility of the aluminum-silicon-copper

alloys. It is stated, for example, that "the copper silicon alloys . . . . . would be used . . . . . where resistance to atmospheric corrosion . . . . . is not required." Such a statement might convey to some the impression that the aluminum-silicon-copper alloys are not at all resistant to ordinary corrosion. As a matter of fact these alloys possess ample resistance to corrosion for most of the uses to which aluminum is put. It is probably only in cases where the maximum resistance to corrosion is required that this factor need be considered.

Under the heading "Physical Properties" Messrs. Basch and Sayre state that alloys in the first group (those containing less than 8 per cent silicon and no copper) "compete directly with the ordinary aluminum casting alloys now in use, as typically the No. 12 alloy, with 8 per cent copper." This statement may suggest to some that these alloys are more nearly equivalent to No. 12 alloy than is actually the case. The facts should not be lost sight of that these alloys possess superior inductility and toughness, superior resistance to corrosion (which is especially important in marine work) and foundry properties superior in some respects to those of No. 12 alloy, but that the yield point and hardness are less than those of No. 12 alloy. There are many applications in which they may be substituted for No. 12 alloy with advantage, but there are likewise some cases in which such substitution would not be advisable. It may also be mentioned that the alloy containing 5 per cent silicon is now used to a considerable extent where an aluminum alloy containing 5 per cent copper was formerly used.

The authors of the paper state that the 13 per cent silicon alloy modified under proper foundry conditions should give over 25,000 pounds per square inch and over 8 per cent elongation in two inches. It has been our experience that it is quite difficult to consistently obtain elongations in excess of 8 per cent. The elongation is often substantially higher, but it is our opinion that with the technical knowledge at present available, 8 per cent is too high a value for specification purposes and that its inclusion in a specification would result in unduly high production costs. A tensile strength of 25,000 pounds per square inch on the other hand is comparatively easy to maintain. The values of strength

and elongation given by Messrs. Basch and Sayre are not consistent in that it is much easier to obtain this strength than to obtain the 8 per cent elongation. The specification we have recommended calls for a minimum tensile strength of 25,000 pounds per square inch with a minimum elongation of 5 per cent.

In regard to the machineability of aluminum-silicon alloys the authors state that when proper precautions are taken they should machine as easily as other commercial aluminum alloys. The precautions referred to seem to be largely in melting and casting practice. Our own experience and the reports we have received from others indicate that even with the best melting and casting practice the aluminum-silicon alloys are more difficult to machine than some other aluminum alloys, as, for example, No. 12. It should not be inferred from this that aluminum-silicon alloys cannot be machined or even that they cannot be machined well, but merely that considerable difficulty may be encountered in commercial practice. The aluminum-silicon alloys are quite soft and tend to drag under the tool, giving a rough surface. There is apparently also a greater wear on the cutting tools.

The values given by Basch and Sayre for the electrical conductivity of the aluminum-silicon alloys appear inconsistent, and are at variance with values obtained by the research bureau of the Aluminum Company of America. They state that the conductivity of the modified 13 per cent silicon alloy is 40 per cent that of copper, while that of the 5 per cent silicon alloy is 35 per cent. Since silicon decreases the conductivity for aluminum, it would naturally be expected that the conductivity of the 5 per cent silicon alloy would be greater than that of the 13 per cent silicon alloy. Our own measurements show a conductivity of 40 per cent for an alloy containing 4.38 per cent silicon, and 34.5 per cent for a modified alloy containing 12.48 per cent silicon.

The authors have given a rather detailed discussion on the method of modifying the 13 per cent silicon alloy by the use of the Pacz flux. They also refer to the use of metallic sodium, stating that they have tried both processes and that the fluxing process appears to give them better results. No attempt will be made in this discussion to describe in detail how this alloy may be modified with metallic sodium, but it may be pointed out that

we have been able to obtain excellent physical properties with metallic sodium and that the procedure is much more simple and much less expensive than the use of the salt flux. One method which we have used consists in preheating a ladle or pouring crucible to approximately 1200 degrees Fahr., placing in the bottom of it an amount of sodium equal to about 0.05 per cent of the weight of the metal which is to be poured into the crucible and then pouring the molten alloy at a temperature of 1450 to 1500 regrees Fahr. into the crucible. The necessary stirring is accomplished by the pouring. The metal is then allowed to stand for a time before casting, the actual time required depending upon the specific conditions employed, including the amount of metal. In this way a 900 pound lot of metal has been modified at a single operation with the attainment of excellent physical properties. The method is more economical than the use of the flux for many reasons, including the fact that the metal temperature required is not so high, the sodium has practically no destructive effect on iron pots, and very much less on crucibles than does the flux, and no aluminum is consumed in the reaction. The process is quite inefficient as the amount of flux required is very much in excess of that theoretically required to produce the necessary amount of sodium.

The authors of the paper discuss the theory of the modification process to some extent, concluding that "the reason for this grain refinement due to modification has not been satisfactorily solved." To those who are interested in this phase of the subject, it may be mentioned that a theory of the modification process has been worked out by the Research Bureau of the Aluminum Company of America, which satisfactorily explains all of the phenomena now known regarding these alloys. This theory is discussed in detail in an article* in Chemical and Metallurgical Engineering.

In connection with the aluminum-silicon-copper alloys reference may be made to the statement of Messrs. Basch and Sayre and that copper forms compounds with both aluminum and silicon. This statement is true, but the impression which might be obtained from it that copper forms compounds with silicon in

*J. D. Edwards and R. S. Archer; *The New Aluminum-Silicon Alloys*, Chemical and Metallurgical Engineering, Sept. 29, 1924, p. 504.

aluminum alloys of the composition discussed does not appear to be true. The constituents of the ternary alloys appear to be:

1. Aluminum-rich solid solution.
2. Substantially pure silicon.
3. The aluminum-copper compound Cu Al_2.

It may also be mentioned that the formula FeSi, assigned by the authors of the paper to a constituent of the aluminum-silicon alloys containing iron as an impurity, is certainly too definite and perhaps incorrect. The exact composition of the constituent is not known. It may be iron silicide, but there is considerable evidence that it is a ternary compound containing aluminum as well as iron and silicon.

AUTHORS' REPLY:

We would fully agree with Mr. Archer that there is a wide range of usefulness for the copper-silicon alloys. Our statement as to their resistance to atmospheric corrosion is possibly too strongly worded. This resistance seems to bear a direct linear relation to the copper content, almost irrespective of whether or not silicon is present, and particularly for the lower copper content alloys, would be satisfactory except for such severe exposures as marine work.

Unmodified alloys containing up to 10 or 11 per cent silicon are of course in occasional use. Our reason for placing 8 per cent as the practical limit is that nothing seems to be gained by addition of silicon beyond that point. Ductility and ultimate strength in the unmodified alloy both become somewhat lower, while susceptibility to impurities, particularly iron, and tendency to segregation of silicon both increase. There is very little, if any, improvement in foundry properties to offset these disadvantages.

As mentioned by Mr. Archer, the low silicon alloys do not have as a high proportional limit of hardness as the No. 12 alloy. Every effort was made in our paper to emphasize that very point and to call attention to the need for redesign where strength is a prime factor. They do, however, compete directly with the No. 12 alloy as a "general utility" alloy in that very wide field of

castings where size of cross section has been governed by other factors than the strength, and it was to that field that we referred.

Machineability is partly a matter of becoming used to the properties of the material which is being machined. The aluminum silicon alloys call for sharp tools and a certain amount of care, but we have not found it difficult to obtain satisfactory surfaces in practice. In connection with this, the comments of Mr. Strauss, the Materials Engineer of the Navy Department, are particularly interesting.

Our experiences with the use of metallic sodium as a modifier were not entirely satisfactory. (1) The nascent sodium formed by the reaction of the sodium fluoride with the molten aluminum seems to be a more powerful agent than the sodium in metallic form. In fact, using Dr. Pacz's method of modification, we have obtained in occasional test bars as high as 15 to 20 per cent elongation. (2) Burning of such metallic sodium as rises to the surface leaves a residue of sodium hydrate, and extreme care must be exercised to prevent carrying it through into the casting, where it may be pocketed and later serve as an active focus of corrosion. (3) There are obvious objections to the presence of metallic sodium about a foundry, even when enclosed in aluminum capsules, which may relatively easily be damaged by rough usage. Further, in the mechanical operation of introducing the capsules by means of a phosphorizer, which was originally recommended, the air in the phosphorizer itself is forced below the surface and bubbles up through the overheated aluminum, causing probably oxidation and also absorption of nitrogen gas by the metal. At any rate, we found this to be the most satisfactory explanation for the greater number of small blowholes which we found to be present in metal modified by this method.

We would strongly urge against the use of iron pots, for reasons unconnected with the effect of the modifying powder upon the iron. The hot molten aluminum readily absorbs iron from the pots, and this is the one impurity which is most deleterious and which is hardest to keep out. Where used the iron pots should always be well covered with protective washes.

The one vital point raised would seem to be the possibility

of obtaining 8 per cent elongation with the modified 13 per cent silicon alloy. Using the sodium fluoride method of modification, and with proper grade of raw material we have been able, after the first preliminary difficulties, to obtain this value or better as regular foundry practice. The 8 per cent figure has been definitely set by the U. S. Navy as its requirement. The alloy must make its way in the world on the basis of quality rather than price, and it would seem unwise not to recognize that fact in specifications.

Our paper was already in press before the valuable discussion of the theory of modification, by Edwards and Archer, had appeared in Chemical and Metallurgical Engineering. Whether the theory there presented will be generally adopted, it is of course too early to tell, even at the present time.

Salvage and Reclamation of Aluminum-Alloy Castings by Soldering and Welding

By Robert J. Anderson, Boston, Mass., and M. Edward Boyd, Clinton, Mich.

Introduction

The object of this paper is to discuss the economic and metallurgical aspects of the salvage of defective aluminum-alloy castings by the usual methods of soldering and welding. As is well known, in the production of aluminum-alloy sand castings, a variable percentage of the castings poured, say 15 per cent on the average, is spoiled because of the occurrence of certain typical defects, e.g., cracks, blows, draws, holes, *et al.* Certain of these wasters admit of salvage by effecting repairs at the defective places, and, in American foundry practice, welding and soldering are the two methods most extensively applied.

Since aluminum became an important engineering material for construction, much time has been spent in developing methods for making joints in the metal and its alloys, and at the present time the usual methods employed in practice are oxy-gas welding and soldering. Electric-resistance and electric-arc welding methods are in use, but these have not yet found general application. The literature on soldering and welding aluminum and its light alloys is quite extensive, but most of the published papers deal with the technique of making welds and soldered joints, and the metallurgical aspects of the subject have been considerably neglected. At the present time, welding is extensively used, in the aluminum industry, as a manufacturing process for the construction of large tanks, vats, and other vessels for use in the chemical industry; in the manufacture of aluminum cooking utensils, e. g., for attaching cast or stamped spouts to spun bodies; in the repair of broken automotive and

machinery parts in aluminum alloys; and in the salvage and reclamation of castings in foundry practice. Soldering should really have very limited application in aluminum work, as will be shown later, but it is employed in the salvage of castings and also for making joints.

With simple castings, the loss due to wasters may be quite low, say 4-7 per cent, but in complicated castings, like crank-case upper halves for 8-cylinder motor cars, it may be as much as 20-25 per cent on the average. Of these losses, some 50 per cent is reclaimed by soldering and welding, and additional reclamation is made of porous and leaky castings by treatment with sodium silicate.

In the present paper, the processes of welding and soldering aluminum and its light alloys and the technique for carrying out preferred procedures will not be discussed even briefly, since these subjects have previously been treated at great length and are well understood. As indicated, the writer's object here is to discuss the salvage and reclamation of defective aluminum-alloy castings which occur in sand founding, and the economic and metallurgical aspects of such salvage as affected by soldering and welding will be emphasized. The reclamation of porous castings by treatment with sodium silicate will not be discussed in this paper.

Casting Losses in Aluminum-Alloy Sand Founding

In the production of aluminum-alloy castings in the sand foundry, the castings made during a day's run may be divided into three classes; viz., (1) good castings, which pass inspection; (2) castings with remediable defects, which can be salvaged; and (3) totally defective castings, which are immediately returned to the melting room. Even with the best practice, a certain number of the castings produced will be found to contain defects, and these defects may admit of repair.

The question of casting losses in aluminum-alloy foundry practice has been treated at length by one of the writers[19*], and the types of defects encountered and the causes for losses have been discussed. In the rough inspection of castings on removal from the molds, the parts may be sorted into three groups, as

*Numbers refer to papers listed in the appended bibliography.

above indicated; viz., (1) good castings, (2) castings with remediable defects, and (3) totally defective castings. On rough inspection, castings are rejected because of the presence of certain typical defects, among which cracks, surface sand holes, crushes, run outs, mis-runs, cold shuts, thin walls, blows, draws, and defects due to the coring are the most prevalent. These sundry defects are directly traceable to one or a combination of causes including too high and too low pouring temperatures, core shifts, sand in the mold and dirty molds, cope drops, improperly made molds, dirty cores, broken cores, cores too hard or too soft, lack of chills, improper gating, wet chills, improperly tempered sand, poor quality of metal, etc. Blowholes, porosity, and unsoundness are related defects of common occurrence, but these are not normally found on rough inspection, and porosity is normally examined for, e.g., in the case of castings which should be leak-proof such as carburetors, manifolds, crankcases, etc., during the course of a special test for this defect. Porosity and related defects, and hard inclusions, may be uncovered on machining.

Of course, it is difficult to draw sharp lines of demarcation among good castings, those with possibly remediable defects, and totally defective castings, and in order to govern castings inspection and salvage it is necessary to adhere to some simple, practical, and understandable set of inspection and salvage specifications. Whether any casting shall be accepted, rejected, or admit of attempted salvage must depend upon the character and amount of the defects, upon the use to which the casting is to be put, upon the amount and character of the subsequent machining in relation to the defects, and upon the inspection specifications. It is quite impossible to state broadly what kinds of defects may be repaired. Specific defects may be large and serious, or situated at such positions on castings that repair is inadmissible, inadvisable, or impossible, or else the same types of defects may be small and innocuous. A defect which may cause one type of casting to be thrown out may be of no importance in another casting.

Speaking first of the usual defects encountered on rough inspection; it may be stated broadly that defective castings containing certain types of defects, provided these are not seriously

large or situated at particular positions on the castings, may be reclaimed. The preferred method of salvage is to weld the defective places, but soldering is employed for certain kinds of defects. In a general way, it may be said that small cracks, local porosity, draws, surface sand holes, certain types of misruns and cold shuts, blows, and the like may be repaired by welding. Soldering is actually employed for repairing blows, cracks, draws, and other defects, but it should be emphasized that soldering should not be applied to the salvage of castings which contain large and serious defects such as long cracks. Soldering should be admissible only for the repair of small and innocuous defects and to improve the appearance of the finished casting.

In the matter of porosity and unsoundness in leak-proof parts, salvage is normally affected by treating the castings, shown to be porous, with a solution of sodium silicate followed by baking. This matter will not be considered here, but will be discussed in a later paper by one of the writers.

In considering the salvage of castings, differentiation should be made between defective castings found on inspection in the foundry and defective castings found on machining. A casting which may pass foundry inspection may be found, on machining, to contain serious internal defects and flaws, owing to the foundry practice. Hard inclusions, strain cracks, and unsoundness may be uncovered on machining, and castings containing such defects may admit of salvage. Moreover, on machining, castings may be undercut, broken, or otherwise spoiled, and repairs may be effected. The total amount of machine-shop returns is variable from 0 to 4 per cent, with an indicated average of 1.5 per cent. The return on Liberty aviation-engine castings was about 1 per cent.

Economic Aspects of Castings Salvage

While there is a large field of application for welding in the production of aluminum and aluminum-alloy manufactures and in the repair of parts failed in service, especially broken automobile castings, the employment of welding in the foundry as a means for salvaging defective castings is of great commercial importance. Soldering is, of course, of little importance in

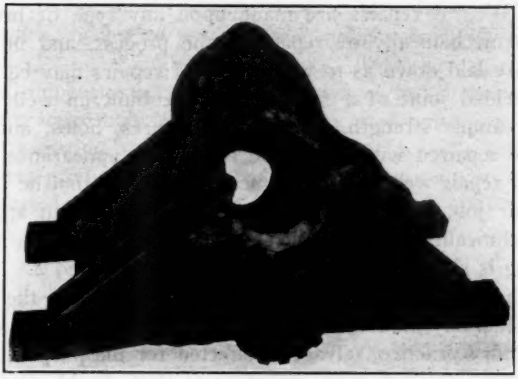

FIG. 1—BROKEN HOUSING, BEFORE WELDING (OXWELD ACETYLENE CO.)

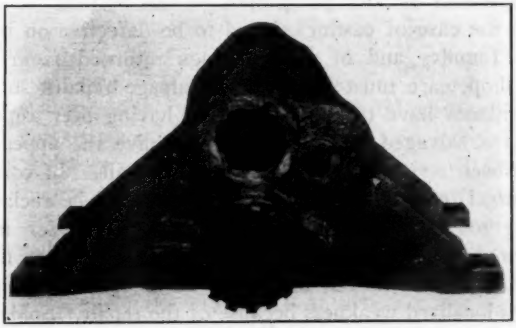

FIG. 2—HOUSING AFTER WELDING; CF, FIG. 1 (OXWELD ACETYLENE CO.)

the production of manufactures, but it does have some legitimate application in castings salvage.

In the job-welding shop, the bulk of the aluminum-alloy work presented for repair consists of broken, or otherwise damaged, crankcases, gear boxes, housings, and other automotive castings. The problem of the job welder is the repair of such broken parts so that they may be put into service with the least

possible delay and at substantial saving over the cost of a new part. Welded repairs are made upon any type of break that admits mechanically of repair by the process, and no restrictions are laid down as to what types of repairs may be effected. The welded joint of a fracture may be built up well so as to ensure ample strength, and large fractures, holes, and breaks may be repaired with no special regard for appearance. In the case of repair welds, the customer understands that he is getting a repair job, and he looks for service rather than appearance and technicalities. The application of repair welding to a broken housing is shown in the accompanying Figs. 1 and 2.

The problem of salvaging defective castings in the foundry is considerably different than that of repairing old broken parts. In foundry practice, salvage is effected for the purpose of making merchantable castings from parts that would otherwise be scrapped because of specific defects, and the economic importance of reclaiming castings containing remediable defects will be shown in later paragraphs of this section.

In the case of castings found to be defective on inspection in the foundry and of new castings returned from the machine shop, care must be taken in salvage repairs so that the part will not have the appearance of having been repaired, or at least a salvaged casting should not have the appearance of having been seriously defective prior to repair. Of course, it is understood that defective new castings should be reclaimed according to sensibly rigid salvage specifications for important parts, and they should never be repaired if there is the possibility that they will fail in service at the point of repair and through localized weakness because of the repair. Solder repairs should be made only rarely (cf. Metallurgical Aspects of the Salvage Problem, below), while weld repairs should not be made on stressed members or on parts whose failure in service might endanger life. A single failure traceable to a casting inadvisedly salvaged by welding or soldering would be many times more expensive, to a manufacturer of motor cars through damage to his reputation, than the cost of a new casting. However, even with strict limitations imposed on foundry salvage, there is considerable scope of application for weld repairs to defective new castings. It should, of course, be emphasized

that such salvage should be carried out only under expert supervision and according to practical and sufficiently rigid specifications.

The importance of castings salvage in aluminum-alloy foundry practice may be properly appreciated only by a consideration of casting losses and the relation of possible salvage to the wasters produced. Table 1 gives some data on casting losses and salvage by welding in the case of aluminum-alloy castings produced in an automotive foundry. Taking the case of the

Table 1

Casting losses and salvage of castings by welding.

Type of casting,	Total number of castings poured,	Number of castings accepted on rough inspection,	Number of castings totally rejected on rough inspection,	Number of castings amenable to salvage by welding,
Variety of automotive castings,	2,093	1,018	267	808
Motor crankcase,	502	270	18	214
Differential housing,	438	242	100	96

variety of automotive castings, out of 2,093 castings poured, about 51 per cent were found defective on first inspection, and of the total defectives some 39 per cent contained defects which admitted of repair by welding. In the other two examples shown in the table, the importance of welding as a method of salvage may be noted. In discussing this matter with three representative founders, the following information was furnished*: In a large automotive foundry, the average casting loss for a variety of automotive castings, but principally crankcases for an 8-cylinder motor car, is 20 per cent, i.e., 20 per cent of the castings poured are rejected on first inspection. Of this loss, some 90 per cent is salvaged by welding. In another automotive foundry, the average casting loss for 6-cylinder crankcases is 10 per cent, and half of this loss is saved by soldering small and localized defects. In still another plant—a large jobbing foundry—the average casting loss is 8 per cent, and some 60 per cent of the loss is reclaimed by soldering or welding, depending upon the type of defect.

*Private communications.

While precise data are not kept in the majority of foundries as to the savings made by salvage, it is obvious that the savings are very substantial. Estimation of the monetary value of the savings effected in the American industry has been made by the writers on the basis of average figures for casting losses, percentage of loss reclaimable, the cost of scrapping castings per pound, and the total production. The first three items are very variable in different plants, depending upon local conditions, but for purposes of calculation the following average figures may be taken; viz., average casting loss, 15 per cent; percentage of loss reclaimable, 50 per cent; and cost of scrapping castings per pound. $0.15. The total output of aluminum-alloy castings may be taken as 100,000,000 pounds per annum. Then, the saving owing to reclamation is of the order of $1,125,000 per annum in the United States. For a plant with a production of 10,000,000 pounds per annum, the saving should be of the order of $100,000 at least. This is a very substantial item and indicates much better than a simple statement the necessity for first-class supervision in the salvage department.

Specifications for the Salvage of Aluminum-Alloy Castings

Generally speaking, the problem of salvaging defective castings in aluminum-alloy foundry practice is not handled in a systematic manner and under metallurgical supervision. Such salvage is usually left in the hands of an inspector, who, in the interest of production, turns all defective castings over to a welder who proceeds to plaster them with solder or else welds everything indiscriminately in the attempt to save all defectives. Although a considerable number of castings are reclaimed by this method of disposition, the general result is that castings which should be welded may be soldered or *vice versa,* and many castings may be ultimately scrapped because of poor repair technique, cracks on welding, or unsightly welds. Moreover, in this way castings containing large and serious defects may be repaired and put into service at the risk of life or the reputation of the manufacturer. Certain types of defects, depending upon their size and situation on the casting, admit of repair, while others are never reclaimable. Inspection of defective castings under com-

petent metallurgical supervision is the only method by which it is possible to determine what defects may be safely and economically repaired.

While no general rules can be laid down to cover the reclamation of defective castings, since salvage depends upon the type of defect, the use to which the casting is to be put, and other important factors, it may be stated broadly that small cracks, surface blows, sand holes, cold shuts, draws, and breaks, are representative of the defects that are repairable by welding. It should be pointed out that in some plants all salvage is done by welding, while in others soldering only is used, while in still others soldering or welding is employed depending upon the nature of the defect. Both soldering and welding have distinct applications in castings repair, and either one should not be used to the exclusion of the other. However, a safe rule to follow is to exclude the use of soldering and to weld all repairable defects. Soldering is prohibited entirely upon rough castings in some shops, but is used on machined and semi-finished castings which cannot be welded because of warping that would ensue. Soldering may be permitted where the joint to be made is free from strains of any kind and where it is not to be exposed to moisture or other agents that would induce electrolytic corrosion between the solder and the casting. Actually, the use of soldering should be quite rigidly restricted, and its primarily useful purpose is to improve the appearance of a finished casting.

As indicated previously, machine-shop scrap is returned to the foundry for repair, and such scrap is the result of (1) machining errors, such as undercuts, oversize holes, imperfect threads, broken taps or drills left in the castings, and the like, or (2) foundry defects, such as may be uncovered on machining. Internal strains in castings are released on machining and, if of sufficient magnitude, may cause cracks.

In considering the types of defects which admit of repair, it is of rather more than passing interest to consider specifications governing salvage. So far as is known, definite salvage instructions are issued in but few plants. The instructions issued at the plant of a motor-car manufacturer and those governing

the reclamation of castings for the Liberty 12-cylinder aviation engine may be cited as representative.

Salvage at an Automotive Foundry:—Taking up first the case of the salvage instructions in force at an automotive foundry, the castings made consist of a wide variety of automotive parts from crankcases to small unions; and in this plant a metallurgist is in charge of the salvage operations. The following general instructions obtain in this plant:

"Aluminum-alloy castings in this plant are to be welded by the arc or oxy-acetylene process, using a cast welding rod of the same composition as the casting to be welded. In all castings except small and plain work and where the defect occurs on the edge and is small, the castings must be pre-heated before welding, and if very large they must be returned to the furnace until a uniform temperature is attained in the part before final cooling to room temperature. In the case of castings which are welded after machining, the machined face of the casting should be clamped to a plate of steel before welding so as to prevent warping."

"While soldering is not prohibited, as little soldering as possible should be done, and all repairs, wherever possible, should be made by welding. The following aluminum-alloy castings may be welded if they contain small foundry defects: Motor fan, switch board, switch-board central-shaft gear housing, motor-gear cover, chain-speed housing, carburetor, intake manifold, transmission case and cover, clutch case, steering-wheel spider, differential carrier, clutch brake-shoe bracket, crankcase oil filler, oil pan, and crankcase."

"In welding rough crankcases before machining, the arc or acetylene process may be used, and unless the defect to be repaired occurs on the edge and is small, the castings should be pre-heated before welding and then again heated so that a uniform temperature exists throughout the casting before cooling. No soldering is permitted on crankcases. It is often impossible to weld crankcases after machining because of warping which will occur, and small repairs on machined cases may be made by soldering. No soldering should be done on any part of a crankcase that is likely to be stressed in service. Defects occurring along the edges and on the cross members of crankcases

can be welded without warping ensuing, and soldering should be avoided whenever possible."

Salvage of Liberty Aviation-Engine Castings:—The detailed salvage instructions drawn up by the Bureau of Aircraft Production[11] during the war for the reclamation, inspection, and disposition of defective aluminum-alloy castings for the Liberty 12-cylinder aviation engine have been published by one of the writers in another place[19]. For the purpose of the present paper, the general salvage of these castings and the particular instructions applying to the crankcase upper half will be given. The following statements are taken almost verbatim from the instructions:

The welding of all rough castings shall be carried out as follows: The entire casting shall be pre-heated to a temperature of approximately 260 degrees Cent., or to a temperature at which the casting will not ring when tapped with a hammer. Defects for repair must be thoroughly cleaned from any sand, oxide, or dirt, which would in any way interfere with the quality of the weld. The castings must be welded immediately after being removed from the pre-heating furnace. The welding stick used must be of approximately the same chemical composition as the casting itself. All welds, when finished, must have the same contour as the original casting. The so-called "burning-in" of castings, which show such defects as mis-runs and cracks, will not be allowed under any consideration. It will not be permissible to weld any cracks on aluminum-alloy castings unless definitely specified in detailed instructions. No welding will be allowed on any ribs of crankcases nor on the propeller end of the cases beyond No. 7 rib. Soldering of any kind will not be permitted on aluminum-alloy castings to be used on the Liberty aviation engine.

Small seepage leaks which are determined by the open-gasoline test may be treated by any of the following methods: (1) bakelite under pressure; (2) bakelite and aluminum powder; (3) boiled linseed oil under pressure, followed by baking; (4) accelerated ageing process; (5) annealing at not over 315 degrees Cent. The use of aluminum powder and sulphur will not be permitted for treating seepage leaks.

Small blowholes or gas pockets, which do not affect the

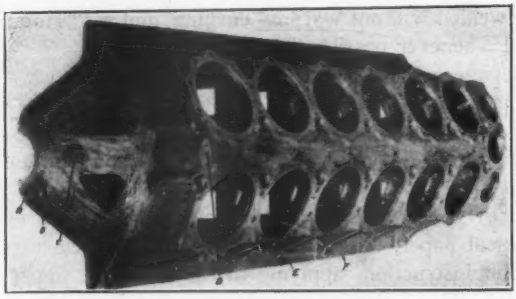

FIG. 3—TOP VIEW, LIBERTY 12-CYLINDER AVIATION-ENGINE CRANKCASE UPPER HALF; PROPELLER END LEFT

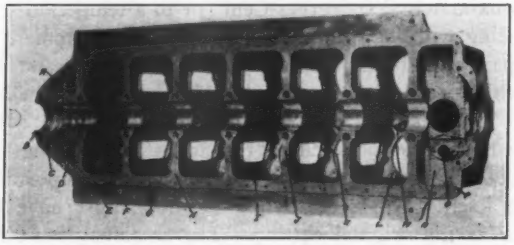

FIG. 4—BOTTOM VIEW, LIBERTY 12-CYLINDER AVIATION-ENGINE CRANKCASE UPPER HALF; PROPELLER END LEFT

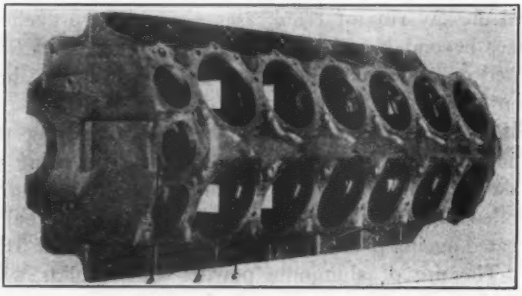

FIG. 5—TOP VIEW, LIBERTY 12-CYLINDER AVIATION-ENGINE CRANKCASE UPPER HALF; PROPELLER END RIGHT

strength of a casting, and which do not leak when treated by the open-gasoline test, shall be accepted as they are.

No castings for use on the Liberty aviation engine shall be treated or repaired in any way which will affect the appearance only.

Referring now to the detailed salvage and inspection instructions which applied to the crankcase upper half for this engine, the following remarks apply to Figs. 3, 4, and 5. The letters below refer to corresponding letters in the photographs.

As regards Fig. 3:

(A) Acceptance or rejection stamp shall be placed on this boss.

(B) Cracks caused by rough handling which run into crankcase flange screw hole are acceptable, provided crack does not extend beyond the hole.

(C) Castings showing porosity in this hole are acceptable, provided casting does not show oil leaks after assembly.

(D) Castings which show hole at this point drilled off center must be referred to the Production Engineering Department for disposition.

(E) Small cracks in ribs indicated, or small pieces broken from these ribs, may be repaired by trimming rib with file until defect is completely removed and no sharp corners remain. Defects of this nature shall not penetrate any rib more than 3/8 inch.

(F) Small cracks on this flange due to rough handling are acceptable, if 1/8-inch hole is drilled at end of crack. No welding of cracks of this nature is acceptable.

As applied to Fig. 4:

(A) Great care shall be taken to see that no castings are accepted showing shrinkage cracks under thrust-bearing retainer and propeller-hub bearing seat.

(B) Castings which show bearing felt-retainer inner wall not less than 1/16 inch are acceptable. Castings showing corners undercut, so that thickness of wall between corners and bolt holes at this point is not less than 1/16 inch thick, are acceptable.

(C) Castings which show holes drilled too near edge of flange are acceptable, providing no oil leaks occur after assembly.

(D) Castings showing leaks in No. 7 bearing by the open-gasoline test indicate presence of blowholes under the bearing, and they shall be rejected.

(E) Cracks which penetrate the flange at this point and stop are acceptable as they are. No welding of this type of defect is permissible.

(F) Cracks which penetrate the flange at this point and stop are acceptable as they are. In case the crack does not run into a hole, then 1/8-inch hole shall be drilled at the end of the crack. No welding is permissible on this type of defect.

(G) Cracks which penetrate to a point not beyond the center line of holes are acceptable when a 1/8-inch hole is drilled at the end of the crack. No welding of defects of this kind is permissible.

(H) Castings showing porosity on surfaces are acceptable, providing they do not show oil leaks after assembly, or after having completed acceptance run. No shellac or other foreign material shall be used for stopping these leaks.

(I) Castings showing holes or mis-runs in webs indicated shall be rejected.

(J) Cracks in ribs indicated are not acceptable.

(K) Cracks at points indicated are not acceptable.

(L) Cracks in bosses are acceptable, provided they are not over 3/8-inch long. In case two cracks occur on the same boss and are not more than 1/8 inch apart, section between cracks shall be removed. A maximum of two cracks will be allowed to a single boss, and there shall not be more than one defective boss to a cylinder.

(M) Depressions in surface due to core fins which are not over 1/16-inch deep are acceptable. In every case, such depressions must be thoroughly cleaned.

(N) Sand holes in this face are acceptable, provided they do not leak on the open-gasoline test. In case small sand holes are found that do not leak, these holes may be repaired by the use of a 1/8-inch aluminum pipe plug. The plug must have at least three effective threads, and it must be screwed in tightly and cut off flush with each side of the casting. No peaning will be allowed. After being repaired, the casting shall undergo an open-gasoline test for leaks.

(O) Sand holes on this face are acceptable, provided they are thoroughly cleaned and do not show oil leaks.

(P) Cracks which penetrate to this depth are acceptable, provided they run into bolt hole. Cracks which do not run into bolt hole or do not extend beyond the center line of the hole are acceptable after a 1/4-inch hole is drilled through the flange at the end of the crack.

The following apply to Fig. 5:

(A) Castings showing porosity on this face are acceptable, provided no oil leaks occur after assembly.

(B) Castings which show porosity on the surface indicated are acceptable, provided no oil leaks occur after assembly.

(C) Castings showing small cracks at this point due to use of oversized stud are acceptable, provided they are less than 3/8-inch long and not more than one crack occurs on each cylinder pad.

Specifications similar to the above have also been drawn for the salvage of other castings for the Liberty aviation engine, including oil pans, camshaft housings, and pistons.

Recommendations for Salvage

For handling the salvage of castings, the writers recommend drawing up definite and detailed instruction sheets to apply to specific castings, as has been done in the case of the Liberty aviation-engine castings specifications. Complete directions should be given for the welding, soldering, or other repair of every kind of casting made, i.e., as to just what defects may be repaired and as to how the repair is to be made. A convenient method for handling this is to work out a specification sheet for each casting on which are given the requisite data. In the preparation of a specification sheet, a careful study is first made of the casting in order to determine what portions are exposed to strain and wear, and the exact function of the part in service should be considered. A sufficient number of photographs of the casting should be shown, with various points on the part indicated by letters or arrows. Typical defects that may occur at particular positions should be discussed briefly and instructions for repair given, i.e., as to where and what kind of defects

may be welded, reference being made to the photographs. With such instructions, there is little doubt as to how to proceed in salvaging castings, and any specific questions can be settled verbally by the supervisor of salvage.

While it is generally best to prohibit soldering on rough castings, i.e., parts rejected on inspection in the foundry, soldering may be permitted for some defects in the case of machined castings which cannot be welded because of warping that probably would ensue. The use of solder should be restricted considerably, and should be employed only to improve the appearance of a finished casting. In general a separate salvage specification to cover the reclamation of machined castings should be drawn.

In the process of salvage, careful record should be kept of the number of castings repaired, whether soldering or welding was used, the number of failures in welding, and other items. Such a record is of value in determining the procedure to follow in salvaging castings from future production, and if proper cost records are also kept the savings effected by the salvage can be known with accuracy.

Metallurgical Aspects of the Salvage Problem

As stated previously, the technique of welding and soldering aluminum and aluminum alloys need not be given attention here since the methods for securing satisfactory joints are well known and have been discussed at length in the literature (cf. appended bibliography). The general question of welding aluminum-alloy castings has been treated in detail by Miller[9] in his book on welding, while the repair and joining of aluminum and aluminum-alloy parts by both soldering and welding have been discussed in a book by Platt[20]. Details as to manipulation and methods for making specific joints and repairs are given in these publications. Methods of soldering are discussed in Circular No. 78 of the U. S. Bureau of Standards[18].

As stated, repairs to defective castings are made by welding or soldering, and while a joint made by welding is vastly superior to one made by soldering, it should be understood that in every case where fracture of a repaired part might cause serious

injury or endanger life, welding should be prohibited, as should, of course, soldering. Welding for the repair of defective castings is done ordinarily by the oxy-acetylene process, and the methods for preparing the parts to be repaired or joined are variable depending upon the type of repair, the facilities at hand, and the ingenuity of the welder. Parts may be repaired by so-called cast welding or "burning in," whereby the casting to be repaired is set up in a mold and liquid alloy poured in to fill up a joint[25]. In the reclamation of defective castings by welding, the problem is not how to weld but rather what may be safely and satisfactorily welded. The supervisor of salvage must be familiar with the use of the castings and be able to decide in doubtful cases, not governed by specifications, whether a defect can be repaired without danger of subsequent failure. Success in the reclamation of aluminum-alloy castings by autogenous welding depends considerably upon the individual skill of the welder, and the welding of aluminum and its alloys is much more difficult than that of iron or steel.

Soldering is employed considerably in the aluminum-alloy casting industry for the repair of defective castings but often quite inadvisedly. The question of soldering aluminum and its light alloys has attracted a great deal of interest on the part of laymen, and many patents—most of them entirely useless—have been taken out for solders, soldering fluxes, and soldering methods purporting to be suitable for use in joining parts. In soldering aluminum and aluminum alloys, as in other technical operations, there are two classes of people; viz., those who recognize that there are technical limitations, and difficulties to be overcome, in all processes, and on the other hand, those who, because the difficulties of a process are great, forthwith conclude that there must be some mysterious and undiscovered method for rendering easy the object to be accomplished. It seems almost as futile to refute the need for methods of soldering aluminum as it is to refute the "hardening-of-copper" myth. The soldering of aluminum has been satisfactorily worked out to the limit of its apparent possibilities, and it is totally useless for joining structures or making important repairs.

While many papers have been published dealing with methods of soldering and welding aluminum and aluminum-alloys,

very little information has appeared concerning the metallurgical aspects of these processes. In discussing the metallurgical aspects of the salvage problem below, comparison will be made between soldering and welding, and the principal metallurgical features of the two processes will be taken up.

Metallurgical Aspects of Welds:—Defective castings are welded by an oxy-gas process, usually by oxy-acetylene welding, and employing a welding stick of the same composition as the casting to be welded. The cast welding or "burning in" of parts is not practiced much in the United States but is used in England to some extent. Castings are usually welded without employing a flux, and the weld is thoroughly puddled with a rod during the operation. Whether a casting should be pre-heated or not for welding depends largely upon the character of the defect to be remedied, but if any defect is large or extends into the body of the casting rather than is confined to an edge, it is advisable to pre-heat the entire casting. Puddling during welding is highly advisable since it ensures good alloying; moreover, puddling is invariably required when no flux is used.

In cast parts, if the weld is properly made, the actual weld may be nearly as strong as the casting. Welding is to be recommended almost invariably in place of soldering, and the former must always be used in repairs where strength is required and when the joint or other repair will be exposed to moisture. A weld will not fail by auto-corrosion or disintegration as is the case with a soldered joint, but a weld may be very unsound because of poor work on the part of the welder. In contradistinction to a soldered joint, where the bond is a weak alloy and made up of metals electronegative to aluminum, a fusion weld may be made of the same composition as the parts to be joined. Thus, a welded joint is strong while a soldered joint is weak, and the former is no more corrodible than the casting while the latter is quite corrodible.

When a weld is made in an aluminum-alloy casting, the casting and the weld material are heated locally to high temperature, and from the metallurgical point of view the melting of aluminum at high temperature when exposed to the air and products of combustion is regarded as harmful. High melting

and pouring temperatures are not satisfactory in the foundry in pouring the original casting, since they give rise to unsoundness and related defects and poor tensile properties. While it is generally agreed that high melting temperatures and overheated metal are to be avoided, recent work by Rosenhain and Grogan[21] indicates that the tensile properties of aluminum are not affected to any marked extent by repeated melting and overheating. If this latter is the case, then the high temperature set up locally by the welding flame impinging on the casting and the overheated condition of the weld puddle might not have deleterious effects, unless an excess of gas is dissolved thereby causing unsoundness, on freezing of the weld, and inter-granular weakness.

There do not appear to be any data available on this subject, but undoubtedly gases are dissolved by the weld portion, and the structure of welds is normally quite unsound. The effect of dissolved gases on the mechanical properties of aluminum-alloy castings is not known, but it is well known that their presence is responsible for blowholes, porosity, and unsoundness, as has been shown by one of the writers[14]. It may also be said that the strength of a casting is very largely dependent upon the amount of porosity—porous castings generally are weak and brittle. It should of course be added that, in heating for welding, aluminum combines with both oxygen and nitrogen at moderate temperatures and very rapidly at high temperatures, so that a weld may contain much occluded dross if the welding temperature is excessively high.

It is quite obvious that a welded joint will not possess the strength of the original casting (both being of identical composition), although it would be easy to gain the impression from welding literature that it is as strong or stronger. The weld is often thought to be stronger than the casting because, in tension, a welded test piece usually fractures outside of the actual weld. This applies to worked parts, and is due to variable grain growth in the vicinity of the weld on heating. Welded castings may break outside of the weld because of local defects in the actual casting which were associated with the defect repaired. The juncture of the weld portion and the parts welded has been shown to be brittle by impact tests, and this is traceable to poor

alloying and to variable grain size in the portions meeting in a plane of weakness. A good weld may be 80 per cent as strong as the actual casting, and with the large factor of safety usually allowed in the design of castings, few failures result if the weld is properly made.

The weld itself may be impaired by large grain size due to the high temperature of the welding process and subsequent failure to puddle the weld pool. General unsoundness of the weld is due to dissolved gases taken up from the air and products of combustion of the welding flame. All welds examined microscopically by the writers have been found to be more unsound than the casting in which the weld was made. Large grain size is undesirable, since large grain size of itself causes weakness, and the juncture of large grains in the weld and smaller grains of the casting, or *vice versa,* sets up a plane of weakness similar to that produced by columnar crystals in a cast alloy. From the point of view of the crystallization of liquid metals upon solidifying, just such zones of weakness as are found in ingots and castings, designed with sharp corners, should be, and often are, present in welds. It is quite plain that the two sets of crystals are distinct and separate and appear not to coalesce at the line of juncture, producing an effect of greater or less discontinuity between the two areas. Also as in the case of large cast ingots, there appears to be, in the majority of cases, a distinct grain boundary definition in the form of non-metallic impurities, i. e., oxide, dirt, etc., that interferes with the cohesion of the metallic grains. This effect could, of course, be destroyed by cold working the weld, thus breaking up the orientation of the crystals and working out the line of juncture between the large and small grains. Usually this procedure is not possible in the case of castings, and annealing the whole casting would have no effect on the grain formation. Considerable information is available[16, 22] upon the crystallization of metals and alloys that would undoubtedly be of value in studying the microstructure and macrostructure of aluminum-alloy welds.

Metallurgical Aspects of Soldered Joints:—While welding is the only method to be recommended for joining aluminum-alloy parts where strength is required or the joint is to be exposed to moisture, it is sometimes desirable, and

more often thought to be desirable, to solder rather than weld. Soldering is accomplished more easily than welding, and it is often tempting to solder instead of weld, especially on machined castings where there is danger of warping by heating. In practice, considerable use is made of soldering for repairing defective castings, and in a great many instances where failure is sure to result. The temperature of soldering is low and warping or distortion of a part rarely occurs; hence pre-heating is unnecessary as is required in welding. Soldering may be regarded as satisfactory if it is desired merely "to stick parts together" and no permanence is required, but ordinarily soldering should be prohibited for the general run of repairs. Soldering is, admittedly, useful for patching holes and other small defects in castings and for improving the appearance of a finished casting, but it should never be used in structural assembly, and actually soldering should have very limited application in aluminum work.

Good solders for aluminum and its alloys usually consist of low-melting point alloys of zinc, tin, and aluminum, but many complex alloys are suggested and used for soldering, and some solders contain copper, lead, iron, bismuth, antimony, and other metals in addition to zinc, tin, and aluminum. The function of metals other than zinc, tin, and aluminum in a solder is not clear, and practically any other added metal should be regarded as useless or harmful. Good zinc-tin solders contain 15-50 per cent zinc and remainder tin, while good zinc-tin-aluminum solders contain 8-15 per cent zinc, 5-12 per cent aluminum, and remainder tin. The tensile strength of a good solder is about 7,000 lbs. per sq. in.—much less than that of aluminum and cast aluminum alloys. The strength of any soldered joint depends upon the type of joint, the solder, and the skill used in soldering, but no dependence can be placed on the strength of joints made by soldering. The effectiveness of a soldered joint depends upon the adhesion between the aluminum and the initial, or "tin," layer of the solder, and an actually perfect alloy at the joint between the solder and the aluminum is difficult to obtain. The higher the temperature at which tinning is done, the better will be the alloying at the juncture.

As indicated, aluminum-alloy parts can be soldered together fairly easily, provided the proper precautions are taken, but in all cases, irrespective of the solder used, the joint is not permanent and fails after a short time on exposure to moisture or humid atmospheres. Soldered joints fail because the metals in the soldering alloys are electro-negative to aluminum, and on contact with water galvanic cells are set up so that the joint disintegrates by auto-corrosion. One of the most severe tests to which a soldered joint can be subjected is that of placing it in steam[5]. Joints which have the appearance of being satisfactory and which are apparently mechanically strong (within the limits of the strength of the solder) fail rapidly when exposed to steam. The joint fails by corrosion and disintegration of the solder and the bond juncture, and soldered joints, when used, should be protected against corrosion by painting or varnishing. Taking the case of tin-zinc-aluminum-lead solders; these metals form eutectiferous systems with each other (except aluminum-lead and lead-zinc), so that such solders actually contain each of these metals in the practically pure state. There has been found little difference between different solders in their electrolytic emf. to aluminum in different solutions; they are all electronegative to aluminum, and electrolytically they act as negative galvanic poles and accelerate the corrosion of aluminum. Moreover, the zinc-base solders are themselves rapidly attacked. Where heavy joints are made in castings, as in repair work, corrosion of the joint near the exposed surface may be of little consequence, but such a joint will be weak at best owing to the original low strength of the solder.

In the use of soldering in salvage, a good rule to follow is never to solder a casting having a defect so large that failure would result if the casting were used without being repaired at all by soldering. Thus, the only use of soldering is to improve the appearance of defective castings.

Microscopy of Fusion Welds and Soldered Joints

In connection with the present study of the salvage problem, microscopic examination was made of a large number of soldered joints and of fusion welds which were made at dif-

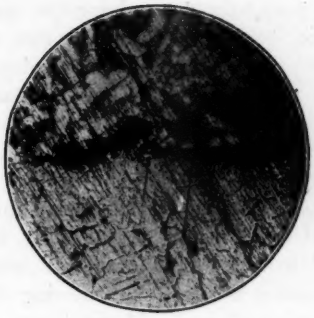

FIG. 6—JUNCTURE OF SOLDER AND ALUMINUM ALLOY; UNSOUNDNESS AT JUNCTURE; SOLDER, UPPER; ALUMINUM ALLOY, LOWER; UNETCHED; X 75.

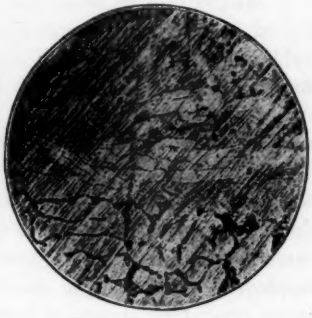

FIG. 7—JUNCTURE OF SOLDER AND ALUMINUM ALLOY; SOUND JUNCTURE; SOLDER, UPPER; ALUMINUM ALLOY, LOWER; UNETCHED; X 75.

FIG. 8—JUNCTURE OF SOLDER AND ALUMINUM ALLOY; SOLDER, UPPER; ALUMINUM ALLOY, LOWER; ETCH $Fe_2(SO_4)_3$; X 250.

FIG. 9—SAME AS FIG. 8; AFTER 17 HOURS' IMMERSION IN TAP WATER; SOLDER, UPPER; ALUMINUM ALLOY, LOWER; X 250.

ferent foundries in the repair of defective aluminum-alloy castings. The castings were made in commercial No. 12 alloy and for welding a stick made of 92:8 aluminum-copper alloy was used. In soldering various commercial solders were employed.

Microscopic examination is useful for determining the quality of soldered joints and fusion welds. Thus, in the case of soldering, the quality of the adhesion of the solder to the aluminum alloy can be noted, and the manner in which corrosion and disintegration of a soldered joint take place on exposure to moisture can readily be examined. In studying the structure of welds, macroscopic methods are useful, since the constitution of the weld is often not so important as its gross macrostructure. In examining soldered joints and welds in the present study, the macroscopic methods suggested by one of the writers[17] were employed. Macroscopic examination is useful in showing the gross crystalline structure both of welds and soldered joints, as well as general unsoundness. If, however, a more searching examination of grain boundaries, junctures, or other features is required, higher magnifications should be used. The quality of any joint can be examined best by polishing a section cut through the weld or soldered joint so as to include both the weld material or the solder, as the case may be, and the stock of the casting. Only a few of many photographs taken are shown in discussing typical features below.

Microscopy of Soldered Joints:—Typical structures found in soldered joints made in 92:8 aluminum-copper alloy castings are shown in the accompanying photographs of Figs. 6 to 11 inclusive. Fig. 6 shows the juncture of the solder and the casting in a case where the joint was poor and unsound. The solder had the composition 66:34 tin-zinc. Fig. 7 shows a similar joint where the juncture is sound and there appears to be alloying between the solder and the casting. Such a structure as shown in Fig. 6, of course, is excessively weak, while the juncture shown in Fig. 7 is about as good as can be secured. Fig. 8 shows another juncture in a soldered joint; the solder used was complex. The joint is sound, but there is a sharp line of demarcation between the aluminum alloy and the solder at the juncture. Fig. 9 shows the microstructure of this juncture after immersion in tap water for 17 hours; the corrosion of the solder is marked.

Fig. 10 shows the macroscopic appearance of a soldered joint in the polished and unetched section; unsoundness at the

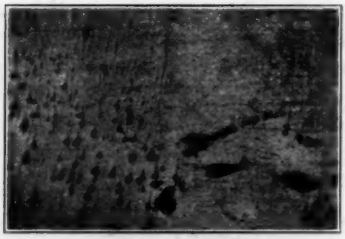

FIG. 10—MACROGRAPH OF SOLDERED JOINT; SHOWING UNSOUNDNESS; SOLDER, LEFT; ALUMINUM ALLOY, RIGHT; UNETCHED; X 4 (VERT. ILL.)

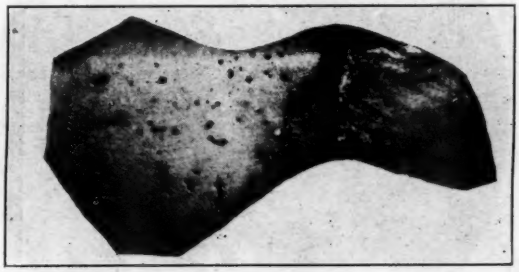

FIG. 11—SOLDERED JOINT, AFTER 68 HOURS' IMMERSION IN TAP WATER; X 5 (REDUCED ONE-HALF IN REPRODUCTION) (VERT. ILL.)

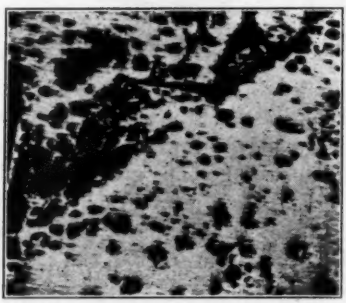

FIG. 12—JUNCTURE OF WELD AND CASTING; GREAT UNSOUNDNESS IN WELD; UNETCHED; X 4 (VERT. ILL.)

joint is slight, but the soldered portion itself is unsound. Fig. 11 shows the appearance of a soldered joint after immersion for 68 hours in tap water; corrosion at the joint is marked.

Microscopy of Fusion Welds:—Some typical photomicrographs of welded joints in repaired 92: 8 aluminum-copper alloy castings are shown in the accompanying photomicrographs of Figs. 12 to 20. Fig. 12 shows a macrograph of a section cut

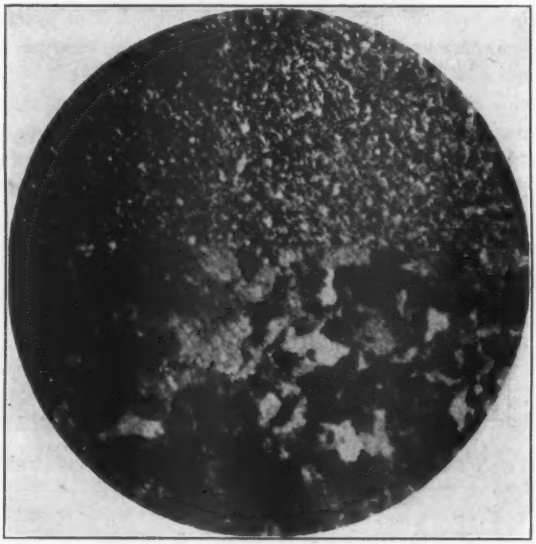

FIG. 13—JUNCTURE OF WELD AND CASTING; SMALL GRAINS OF WELD, UPPER; LARGE GRAINS OF CASTING, LOWER; ETCH NaOH; X 4 (OBL. ILL.)

through a weld in a casting; the area in the upper left-hand half represents the alloy added by welding, while the other half represents the original casting. The great unsoundness of the weld may be noted. Fig. 13 is a macrograph of a sound weld, showing the marked difference in grain size between the alloy in the weld and that in the adjacent stock of the casting; in the macrograph, the upper area (relatively fine grained) represents the alloy of the weld, and the lower area (coarse grained) represents the alloy of the casting. Fig. 14 is a macrograph showing un-

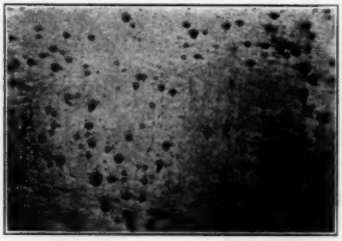

FIG. 14—MACROGRAPH SHOWING UNSOUNDNESS IN A WELD; UNETCHED; X 4 (VERT. ILL.)

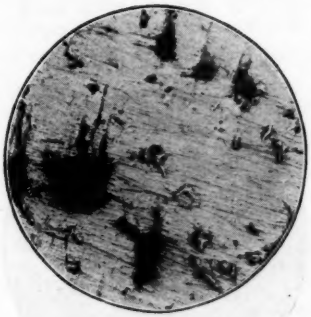

FIG. 15—MICROGRAPH OF SAME WELD AS IN FIG. 14; UNETCHED; X 75.

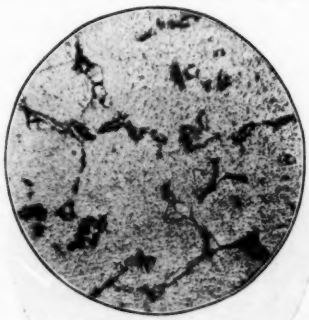

FIG. 16—MICROSTRUCTURE OF 92:8 ALUMINUM-COPPER ALLOY; IN THE CASTING, NEAR THE WELD; ETCH NaOH; X 150.

soundness in an actual weld, while Fig. 15 is a micrograph of the same weld.

Fig. 16 shows the microstructure of a 92:8 aluminum-copper alloy casting, and Fig. 17 shows the structure in an adjacent weld. Figs. 18 to 20 inclusive make up a series of three photomicrographs, at low magnification, taken across a welded area. Fig. 18 shows the structure of the alloy in the casting; Fig. 19 shows the structure at the juncture of the weld and the casting; and Fig. 20 shows the structure of the actual weld area. The structures are self-explanatory.

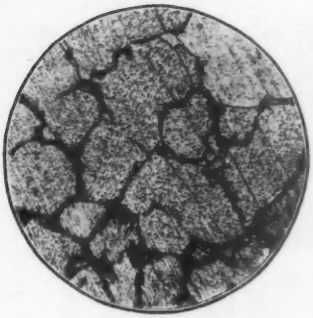

FIG. 17—MICROSTRUCTURE OF WELD (CF. FIG. 16); ETCH NaOH; X 150.

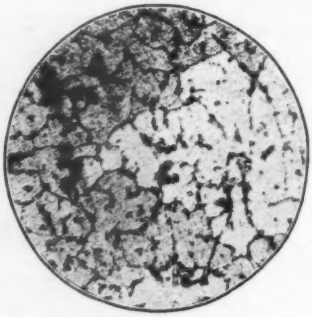

FIG. 18—STRUCTURE OF THE ALLOY IN A WELDED CASTING; ADJACENT TO THE WELD (CF. FIGS. 19 AND 20); ETCH NaOH; X 150.

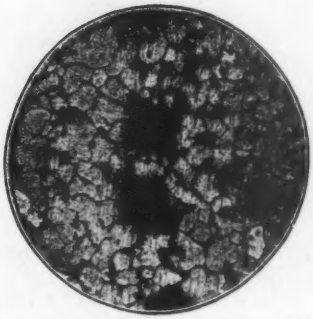

FIG. 19—STRUCTURE AT THE JUNCTURE OF THE WELD AND THE CASTING (CF. FIGS. 18 AND 20); ETCH NaOH; X 150.

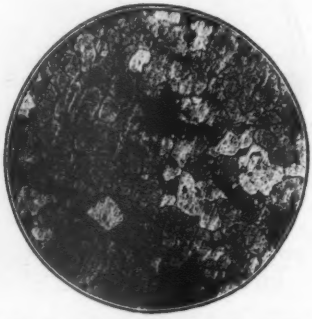

FIG. 20—STRUCTURE OF THE WELD PORTION (CF. FIGS. 18 AND 19); ETCH NaOH; X 150.

In welding, there is actual alloying at the juncture of the solid casting and the weld portion, and superficially examined there may not appear to be great difference between the structure of the weld portion and that of the adjacent casting. The differences are, of course, readily revealed on etching for macrostructure and on microscopic examination. Both microscopic and macroscopic examination have shown that the grain size of the alloy in the actual weld portion is smaller than that of the orig-

inal casting, i.e., in welded sand castings. A weld is usually quite unsound, and its relative unsoundness may be compared with that of the original casting. Fractures of welded castings might be expected to occur at the juncture, either because of unsoundness at the joint owing to films of aluminum oxide, or to discontinuity of structure due to the large and small grains meeting in a plane of weakness.

Summary and Conclusions

In the foregoing, the attempt has been made to indicate the importance of properly conducted salvage of defective aluminum-alloy casting in foundry practice, and the economic aspects of the problem have been emphasized. It is hoped that the information given will be of use to foundrymen in reclaiming wasters arising in production and will be of interest to engineers in considering the dangers of improperly salvaged castings.

Summary

The paper may be summarized briefly as follows:

1. Casting losses in aluminum-alloy foundry practice may be taken as about 15 per cent on the average, of which at least 50 per cent may be salvaged by welding or other repair.

2. Founders making aluminum-alloy castings in important amounts can profitably standardize their salvage methods.

3. In a foundry with a production of 10,000,000 pounds of finished castings per annum, the saving effected by reclaiming defective castings may amount to $100,000 per annum.

4. The important problem in salvaging castings in the foundry is to determine the class and nature of defects that may be safely and economically repaired.

5. Detailed salvage instructions should be drawn up to cover the reclamation of defective castings. (Typical instructions are described in this paper.)

6. In considering the metallurgical aspects of the salvage problem, it has been shown that welding is to be preferred to soldering for the repair of defects and that soldering has few legitimate applications.

7. Soldered joints are mechanically weak and very liable to corrosion and disintegration.

8. Welds in aluminum-alloy castings tend to be unsound, and this contributes to the weakness of welded joints.

9. Failures of welded joints may occur through the weld because of local weakness of the weld portion itself or at the juncture of the weld and the casting, i.e., at the joining plane of large and small grains, where there is discontinuity of structure.

10. Typical photomicrographs of soldered joints and fusion welds have been given.

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25. Anon. *Cast welding or burning fractured aluminum-alloy castings.* The Metal Ind. (London), vol. 23, 1923, p. 18.

Discussion—Salvage of Aluminum Alloy Castings by Welding and Soldering

JESSE L. JONES: In looking over this paper I see that the authors have laid considerable stress on the value of the preparation of castings before welding is attempted; also the question of heating the castings is considered of great importance. Then the joints are supposed to be well puddled in order to get a good union between the welding materials and the casting. A fourth injunction is that the alloy used be similar to the allow of which the casting is composed. The authors do not favor particularly the burning in process which is so familiar to foundrymen and which is used to some extent in reclaiming castings. I suppose one of the objections to this burning in process is the fact that the castings are likely to be cracked unless the operation is conducted with very great care. The process of soldering is not applicable except to improve the appearance of the casting. Of course the ordinary solders used have no very great strength; possibly the solder that has given the best results is the so-called Richards aluminum solder, composed of aluminum, tin, zinc and some phosphorus. This solder requires no flux, the phosphorus itself acting as a flux. While at the Hamburg convention last year I was very much interested in a process of reclaiming aluminum castings and forgings which was shown, and some of the examples were very remarkable. This was a modification of the Schoop process, or the spraying of aluminum and other alloys. Test pieces were shown made from aluminum by the process which had the strength of ordinary cast aluminum, and there were also pieces shown made of copper ni-crome and gun bronze. Tea kettles and other hollow-ware of aluminum were welded in this way, and as far as could be ascertained, the weld was just as good as the original material. Some of the test pieces had excellent elongation, in fact, equivalent to the tests of the original material. I mentioned this process to C. M. Sager, Jr., of the Bureau of Standards, who is doing some work along this line. He has a modified Schoop process in which he has a reducing gas or a neutral gas surrounding the particles of metal. This is supposed to give a better weld, because it is not full of oxidized particles. Mr. Sager prepared some test pieces of zinc, tin and lead, I am not so sure about the zinc, but tin and lead, and showed me that he obtained just as good tensile characteristics in elongation with sprayed metal as he did with the cast tin and lead. He said he had not had an opportunity to do any work on copper or ni-crome, but this process of welding seems to me to have considerable of promise in it.

Report of Committee on Grey Iron Castings

To the Members of The American Foundrymen's Association:

Your committee on grey iron submits the following report of its activities during the year 1923-1924 for your approval:--

1. With great regret we acknowledge the death of H. E. Diller of the Penton Publishing Company and a member of your committee. Mr. Diller's work has always been sincerely appreciated. His loss will be keenly felt in our activities.

2. Due to the vacancy, caused by the death of Mr. Diller, Mr. George Drysdale of the Penton Publishing Company was elected a member of your committee. Mr. Drysdale's wide experience in the grey iron field should make him a valuable asset to us.

3. On May 2, 1923, your committee resolved to hold a meeting at the Hotel Gibson, Cincinnati, Ohio, some time between that date and the time of the convention of the American Society for Testing Materials in Atlantic City in June. This meeting was to be primarily for discussing the adoption of an International Test Bar. Due to the inconvenience of Cincinnati as a meeting point, the committee assembled at the Statler Hotel, Detroit, Michigan, on December 15, 1923.

4. The members present were:—

H. B. Swan (Chairman), Cadillac Motor Car Company.
E. J. Lowry (Secretary), Hickman, Williams & Co.
R. S. MacPherran--Allis-Chalmers Mfg. Corporation.
Willard Rother—Buffalo Foundry & Machine Company.
J. D. Stoddard—Detroit Testing Laboratories.
H. E. Diller—Penton Publishing Company.
Visitors (Members of the A. S. T. M. Committee A-4).
Doctor Richard Moldenke—Watchung, N. J.
Walter Wood—R. D. Wood & Co.
Members absent:—
Jesse Jones—Westinghouse Electric & Mfg. Co.
George Elliott—Lunkenheimer Company.

5. The minutes of the meeting are substantially the same as reported in the trade papers, a copy of which follows:—(The A. F. A. committee was asked to work in conjunction with the International Test Bar committee on the question of an international test bar.)

On the international test bar committee are representatives from eight countries—the United States, England, France, Spain, Italy, Belgium, Switzerland and Czecho-Slovakia. E. Ramas of France is chairman and E. Ronceray of Paris is the secretary. H. B. Swan is the American member.

It was decided at the Detroit meeting that the lines of inquiry preliminary to the selection of an international arbitration bar include (1) the relation of different sizes and shapes of test bars to be used in determining the quality of the iron in the ladle, and (2) the relation of the test bar to the casting.

The committee recommended that preference be given the transverse test in the investigations that are to be made. It was decided also to investigate a shrinkage chill test bar invented by Mr. Lowry.

The procedure which the committee recommends to foundries participating in its work is stated as follows:—

(1) Experimental work shall be done on round test bars. The diameters of the test bars to be considered shall be 1.2, 1.3, 1.4 and 1.5 inches. The bars shall be cast on end, one to a mold, 21 inches long and shall be tested on 18 inch centers. The design of the bar shall be similar to the present A. S. T. M. bar with the alteration in dimensions noted above. The molds shall be either made of dry sand or cores. The test bars shall not be tumbled or machined, and in case of shipment over railroads to a point where they may be tested, the test bars shall be packed in sawdust or some similar material.

(2) There shall be at least twelve bars of each diameter cast from a heat and these bars shall be cast from the same ladle. Six of the bars shall be tested by the maker and the remaining six bars shall be sent to the committee, care of E. J. Lowry, secretary, Chicago, for supplementary tests. The analysis of the sets of test bars shall be sent to the committee along

with the results of the individual foundry strength tests. The analysis should cover carbons, silicon, sulphur, phosphorus and manganese.

(3) The test bars shall be numbered from 1 to 12 and in such a way that their identity may not be destroyed, i. e., such as the heat number and maker's mark.

(4) In order to effect knowledge of the English method of testing, the following shall be pursued: Test bars, 12 in number, molded singly on end, in dry sand or core molds, shall be made by individual foundries. These bars shall have the following dimensions: 0.875 inch diameter, 15 inches long, 1.2 inches diameter, 21 inches long and 2.2 inches diameter, 21 inches long.

(5) These bars shall be tested in accordance with the plan set forth above. The 0.875 inch bar shall represent castings up to ¾ inch section; the 1.2 inch bar, up to 2 inch section castings and the 2.2 inch bar, above 2 inch section castings. These bars shall be tested on supports 12 inches and 18 inches apart.

(6) Factors shall be determined to correlate these various diameter test bars to the 1.2 inches diameter strength.

6. As a result of the Detroit meeting, the following members made up their test bars in accordance with the specification noted in section No. 5 of this report:

Walter Wood—R. D. Wood & Company
Willard Rother—Buffalo Foundry & Machine Co.
H. B. Swan—Cadillac Motor Car Co.
R. S. MacPherran—Allis-Chalmers Mfg. Corporation.

Doctor Moldenke kindly favored us with his efforts in breaking and assembling data on the R. D. Wood & Company's test bars. Dr. Moldenke's work was most sincerely appreciated by the committee.

7. The results of all the tests were sent to the secretary of the committee, who transmitted the complete sets of figures to the committee members for their opinions.

8. A copy of the results are attached as Appendix A.

9. As a result of the letter of July 24th, 1924, by letter

vote the 1.2 inch diameter test bar by 18 inches long was adopted.

The vote	1st choice	2nd choice
H. B. Swan	1.20 diam	1.30 diam.
E. J. Lowry	1.20 "	1.30 "
Jesse Jones	1.20 "	
George Elliott	1.20 "	
R. S. MacPherran	1.20 "	1.30 "
Willard Rother	1.20 "	
Walter Wood	1.20 "	
Dr. R. Moldenke	1.20 "	1.30 "
George Drysdale	1.20 "	1.30 "

The vote was unanimous for the 1.2 inch bar to represent "the character of the metal in the ladle from which it was poured and not to be representative of the castings made from the ladle of iron."

10. The notification of the committee members is as follows:

August 11th, 1924.

To the Members of the American Foundrymen's Association's Committee:—

This is to advise you that on August 9th by the unanimous vote by letter of the members of your committee, the 1.2 inches diameter test bar, 18 inches long, has been accepted as the dimensions of the test bar which will be put forward tentatively for the acceptance of the American Foundrymen's Association in October.

This information is not for publication and should not be released under any consideration, due to the fact that there are other important matters which attach themselves to the acceptance of this bar and which have a great relative bearing upon same. I impart this information to you so that you will know of the progress which has been made. I hope that the time will be sufficient so that I may send typewritten copies of the full report to be rendered by the committee to the association in November before sending it to the printer. But, if time does not permit, your secretary assures you that only the information which has been incorporated in letters will find its way into this report.

Respectfully yours,
E. J. Lowry, *Secretary.*

11. The committee still has before it the investigation of the Fremont Portevin method of testing cast iron. This should be completed in the near future. The machine is now in the

hands of H. B. Swan, who is performing one series of tests with it at the present time.

12. There is no action to be reported on the pig iron and grey iron casting investigation.

13. This report is submitted to the American Foundrymen's association with the hope that it will be accepted and placed before other societies interested in grey iron casting work.

14. The chairman extends to his associates his thanks for their cooperation.

Respectfully submitted,

E. J. Lowry, *Secretary.*

Approved, H. B. Swan, *Chairman.*

APPENDIX A

July 24th, 1924.

To the Members of the American Foundrymen's Association's Committee:

At last I have been able to complete the work of getting all the data of the grey iron test bar together. I am submitting the bare figures to you with the hope that you will, within the next few days, look them over and give me an expression of your ideas as to which diameter test bar should be accepted.

I regret that I am unable to furnish you deflection curves for each one of these test bars. Dr. Moldenke was the only one who furnished complete curves, and I have no way of transposing those for your edification. You must accept for the present what few suggestions I might make regarding these curves.

After several weeks of study and analysis of the facts submitted, my conclusions are that either the 1.2 or the 1.3 inch diameter test bars are acceptable to the foundry trade at large. The .875 inch is too small for any accurate results. The 1.4, 1.5 and 2.2 inch bars are too heavy for the average testing machine. This is especially true with the 2.2 inch, which requires practically 15,000 pounds to break it. There is, further, a question of good castings in comparison to the weight of these bars.

I have found that the .875 inch diameter gives but 33 1-3 per cent good castings, while the 1.2 inch gives 59½ per cent; the 1.3 inch gives 54.1 per cent good castings; the 1.4 inch gives 60 4-5 per cent; and the 1.5 inch, 75 per cent.

The factor of good castings is essential to the foundryman in producing test bars, because he ordinarily casts but one set and should these be flawed, he would lose the opportunity of establishing a record for his heat.

The question of deflection:

The .875 inch bar gave a very erratic deflection curve; the 1.2 and the 1.3 inch bars gave a very good deflection; the 1.4, 1.5 and 2.2 inch bars gave good deflection curves, but the factor of the load required to break them places them out of consideration.

I would like to get from you at the most early date your expression of what you believe regarding these test bars. In fact, I would like to have a vote, stating the diameter test bar you favor. You could have as many choices as you want, making a first, second and third choice, etc., but let us make it definite so that we can get something ready for the convention in October.

Everyone is expressing interest regarding the international test bar and I believe it is the most opportune time to get something before the public, so please act upon this as early as possible.

Very truly yours,

E. J. Lowry, *Secretary.*

Table 1

REPORT OF TRANSVERSE TEST—CAST IRON BARS—CADILLAC MOTOR CAR CO.

Bar No.	Approx. Diameter.	Actual Diameter. A.	Actual Diameter. B.	Distance on Centers, Inches.	Load for Each 1/10-inch Deflection. .1	.2	.3	Broke at.	Fibre Stress Pounds.	Equivalent to 1¼-inch A. S. T. M. Bar, 12-inch Centers.	Average.	Analysis.
2	1.5	1.59	1.65	18	1600	3050	2825	.35	42000	2685	3000	Total carbon.. 3.52
4	1.5	1.54	1.60	18	1850	3200	4050	.31	47200	3017		Graph. carbon.. 3.05
6	1.5	1.53	1.50	18	1875	3400	3400	.32	45500	2908		Comb. carbon.. .47
8	1.5	1.55	1.51	18	1900	3400	4000	.29	52100	3330		Manganese .... .41
10	1.5	1.53	1.51	18	1650	3100	3200	.23	41800	2670		Sulphur ..... .077
12	1.5	1.54	1.49	18	1700	3250	4000	.28	53100	3388		Silicon 2.10
												Phos. ..... .17
2	2.2	2.15	2.22	18	5400	10650	11875	.30	50700	3241	3226	Total carbon.. 3.46
4	2.2	2.18	2.24	18	5200	10175	12300	.29	51600	3294		Graph. carbon. 3.02
6	2.2	2.15	2.20	18	4900	10100	11225	.26	49300	3151		Comb. carbon.. .44
8	2.2	2.16	2.23	18	5400	10800	11625	.27	49500	3164		Manganese ... .46
10	2.2	2.16	2.21	18	4800	9800	11425	.28	49500	3164		Sulphur ..... .079
12	2.2	2.18	2.20	18	5000	10700	12125	.29	52300	3343		Silicon 2.04
												Phos. ..... .20
2	.875	.912	.876	12	650	1450		.19	63200	4040	3766	Total carbon.. 3.42
4	.875	.900	.896	12	900	1250		.17	52800	3375		Graph. carbon. 2.93
6	.875	.910	.910	12	750	1300		.18	52700	3369		Comb. carbon. .49
8	.875	.927	.891	12	875	1525		.20	63100	4033		Manganese .... .65
10	.875	.912	.891	12	850	1425		.20	60200	3848		Sulphur ..... .08
12	.875	.904	.900	12	925	1475		.19	61500	3931		Silicon 2.47
												Phos. ..... .17
2	1.4	1.46	1.44	18	1325	2725	3550	.35	55700	3560	3525	Total Carbon.. 3.51
4	1.4	1.45	1.43	18	1825	3000	3600	.30	55600	3554		Graph. carbon. 3.05
6	1.4	1.47	1.42	18	1500	2800	3400	.30	51800	3311		Comb. carbon.. .46
8	1.4	1.475	1.43	18	1550	2900	3575	.30	54600	3490		Manganese ... .59
10	1.4	1.46	1.43	18	1600	2950	3675	.35	57000	3644		Sulphur ..... .099
12	1.4	1.48	1.42	18	1450	2900	3675	.35	56200	3592		Silicon 2.18
												Phos. ..... .25

(Continued on page 434)

Table 1

REPORT OF TRANSVERSE TEST—CAST IRON BARS—CADILLAC MOTOR CAR CO.

(Continued from page 433)

Bar No.	Approx. Diameter.	Actual Diameter. A.	Actual Diameter. B.	Distance on Centers, Inches.	Load for Each 1/10-inch Deflection. .1	.2	.3	Broke at.	Fibre Stress Pounds.	Equivalent to 1¼-inch A. S. T. M. Bar, 12-inch Centers.	Average.	Analysis.	
2	1.3	1.31	1.31	18	1150	2050	2600	.30	63000	3388	3588	Total carbon..	3.46
4	1.3	1.30	1.31	18	1325	2200	2800	.30	56800	3631		Graph. carbon.	3.02
6	1.3	1.32	1.32	18	1300	2300	2975	.30	59300	3791		Comb. carbon.	.44
8	1.3	1.32	1.32	18	1100	2250	2725	.30	54400	3477		Manganese ...	.61
10	1.3	1.35	1.35	18	1300	2350	3000	.30	55700	3560		Sulphur	.097
12	1.3	1.31	1.32	18	1225	2175	2675	.30	52900	3381		Silicon	2.25
												Phos.	.24
2	1.2	1.26	1.22	18	850	1350	2000	.30	48700	3113	3060	Total Carbon..	3.61
4	1.2	1.28	1.23	18	750	1425	1950	.30	46700	2985		Graph. carbon.	3.20
6	1.2	1.28	1.24	18	....	....	1900	.30	44000	2812		Comb. carbon..	.41
8	1.2	1.27	1.23	18	900	1550	1950	.35	49300	3151		Manganese ...	.71
10	1.2	1.25	1.23	18	950	1550	1900	.30	46000	2940		Sulphur	.094
12	1.2	1.28	1.23	18	1050	1750	2125	.30	52600	3362		Silicon	2.28
												Phos.	.21

Table 2

REPORT OF TRANSVERSE TEST—CAST IRON BARS

ALLIS-CHALMERS MFG. CO.

BROKEN BETWEEN 18 INCH SUPPORTS

Size of Bar	Deflection in inches at 1000 pound intervals					Deflection in inches at breaking load	Corrected breaking load Corrected to— 1.2″ round 1.3″ round 1.4″ round or 1.5″ round respectively	Corrected breaking load Corrected to— A S T M standard arbitration bar size 1.25″ round
	1000	2000	3000	4000	5000			
1.2″	.070	.160				.270	2377	2688
1.2″	.075	.165				.290	2519	2848
1.2″	.075	.170				.330	2701	3052
1.2″	.070	.165				.300	2638	2983
1.2″	.080	.180				.280	2394	2706
1.2″	.074	.168				Av. .294	2526	2855
1.3″	.060	.120	.200			.290	3299	2930
1.3″	.060	.120	.220			.265	3056	2715
1.3″	.070	.140	.265			.265	2868	2349
1.3″	.060	.120	.210			.300	3247	2886
1.3″	.060	.130	.220			.270	3017	2681
1.3″	.050	.120	.210			.260	2985	2654
1.3″	.060	.125	.212			.275	3079	2736
1.4″	.040	.090	.150	.220		.290	3941	2806
1.4″	.040	.100	.170	.240		.290	3914	2787
1.4″	.040	.090	.155	.240		.270	3863	2749
1.4″	.050	.090	.155	.230		.280	4021	2862
1.4″	.040	.090	.150	.215		.280	3887	2765
1.4″	.042	.092	.156	.229		.282	3925	2794
1.5″	.03	.065	.105	.150		.230	4547	2630
1.5″	.03	.070	.120	.170		.280	4840	2799
1.5″	.03	.070	.110	.165	.235	.280	4890	2827
1.5″	.03	.070	.115	.170	.230	.310	5436	3146
1.5″	.035	.080	.120	.170	.240	.280	5217	3020
1.5″	.025	.055	.095	.145		.240	4619	2672
1.5″	.030	.068	.111	.162	.235	.270	4925	2849

Analysis:

Total carbon	3.43
Silicon	1.43
Sulphur	.131
Phosphorus	.43
Manganese	.48

Table 3

REPORT OF TRANSVERSE TEST—CAST IRON BARS

ALLIS-CHALMERS MFG. CO.

BROKEN BETWEEN 18 INCH SUPPORTS

Size of Bar	Deflection in inches at 1000 pound intervals				Deflection in inches at breaking load	Corrected breaking load — Corrected to — 1.2″ round 1.3″ round 1.4″ round or 1.5″ round respectively	Corrected breaking load — Corrected to — A S T M standard arbitration bar size 1.25″ round
	1000	2000	3000	4000			
1.2″	.10	.21			.28	2084	2357
1.2″	.10				.26	1858	2099
1.2″	.10	.23			.27	1928	2170
1.2″	.10	.22			.31	2162	2443
1.2″	.09	.21			.28	1965	2220
1.2″	.09	.21			.26	1968	2226
1.2″	.097	.216			Av. .277	1994	2253
1.3″	.08	.16			.28	2578	2292
1.3″	.08	.16			.26	2467	2193
1.3″	.07	.16			.26	2437	2177
1.3″	.08	.17			.28	2436	2168
1.3″	.07	.16			.27	2486	2300
1.3″	.07	.15			.26	2457	2183
1.3″	.075	.160			Av. .268	2477	2219
1.4″	.06	.12	.20		.26	3152	2242
1.4″	.06	.13	.21		.27	3191	2268
1.4″	.06	.13			.25	2963	2108
1.4″	.05	.12	.20		.25	3024	2153
1.4″	.05	.13	.21		.25	2948	2098
1.4″	.06	.12	.20		.27	3157	2246
1.4″	.057	.125	.204		Av. .258	3072	2186
1.5″	.05	.10	.15	.24	.29	3750	2170
1.5″	.06	.11	.16		.25	3596	2076
1.5″	.05	.09	.13	.19	.26	3736	2162
1.5″	.04	.08	.13	.20	.24	3772	2184
1.5″	.04	.09	.14		.23	3418	1978
1.5″	.04	.08	.13	.20	.26	3762	2177
1.5″	.047	.092	.140	.200	Av. .255	3672	2125

Analysis:

Total carbon	3.48
Silicon	1.91
Sulphur	.093
Phosphorus	.58
Manganese	.47

Table 4

REPORT OF TRANSVERSE TEST—CAST IRON BARS—BUFFALO FOUNDRY & MACHINE COMPANY.

Dia. of Bar.	Span, Inches.	Transverse Load.	Deflection.	Remarks.
		1020	.140	Total load for six bars, 6045 pounds.
		980	.120	Average load per bar, 1007 pounds.
.875	12	1070	.130	Total deflection for six bars, 8.10 inches.
		975	.130	Average deflection per bar, .135 inches.
		950	.130	Difference between max. and min, load, 120
		1030	.160	pounds.
		1610	.150	Total load for seven bars, 11165 pounds.
		1790	.170	Average load per bar, 1595 pounds.
		1520	.250	Total deflection for seven bars, 1.34 inches.
1.20	18	1540	.200	Average deflection per bar, .191 inches.
		1605	.210	Difference between max. and min. load, 270
		1525	.150	pounds.
		1575	.210	
		1800	.200	Total load for nine bars, 16900 pounds.
		1870	.200	Average load per bar, 1877 pounds.
		1830	.190	
		1955	.230	Total deflection for nine bars, 1.850 inches.
1.30	18	1825	.160	Average deflection per bar, .206 inches.
		1900	.240	Difference between max. and min. load, 165
		1880	.220	pounds.
		1965	.170	
		2565	.230	Total load for six bars, 14235 pounds.
		2535	.200	Average load per bar, 2372 pounds.
1.40	18	2450	.150	Total deflection for six bars, 1.19 inches.
		2210	.160	Average deflection per bar, .198 inches.
		2360	.230	Difference between max. and min. load, 450
		2115	.220	pounds.
		2775	.180	Total load for six bars, 16905 pounds.
		2845	.170	Average load per bar, 2817 pounds.
		2735	.210	Total deflection for six bars, 1.260 inches.
1.50	18	2900	.250	Average deflection per bar, .210 inches.
		2760	.220	Difference between max. and min. load, 175
		2900	.230	pounds.
		8510	.150	Total load for six bars, 5258 pounds.
		9025	.160	Average load per bar, 8763 pounds.
		8175	.160	Total deflection for six bars, 1.06 inches.
2.20	18	8670	.200	Average deflection per bar, .177 inches.
		8900	.200	Difference between max. and min. load, 1125
		9300	.190	pounds.

Analysis:

Silicon	1.50
Sulphur	.080
Phosphorus	.240
Manganese	.80
Carbon	3.20

Table 5

REPORT OF TRANSVERSE TEST—CAST IRON BARS—R. D. WOOD & CO.
DATA FOR THE COMPLETE CURVES OF THE SEVERAL TEST BARS.

Load in Pounds.	Bar Diameters in Inches 0.875	1.20	1.30	1.40	1.50	2.20
0	0.000	0.000	0.000	0.000	0.000	0.000
100	.018					
200	.037	.009	.009	.005	.004	
300	.063					
400	.093	.024	.022	0.12	.010	
500	.127					
600	.157	.040	.033	.021	.016	
700	.191					
800	.216	.058	.045	.030	.022	
1000	....	.075	.059	.042	.031	
1200	....	.098	.078	.055	.041	
1400	....	.122	.096	.069	.052	
1600	....	.154	.116	.081	.062	
1800	....	.174	.137	.094	.071	
2000	....	.185	.166	.109	.082	
2200	....	....	.204	.126	.090	
2400	....	....	....	.146	.109	
2600	....	....	....	.171	.122	
2800	....	....	....	.193	.133	
3000	....	....	....	.210	.147	
3200	....	....	....	....	.166	
3400	....	....	....	....	.187	
3600	....	....	....	....	.202	

Table 6

REPORT OF TRANSVERSE TEST—CAST IRON BARS—R. D. WOOD & CO.
ANALYSIS OF TEST BAR SETS.

American Test Bar Sets:
1.20 inches, 1.30 inches, 1.40 inches, 1.50 inches Diameter Bars.

Silicon specifications	1.75	2.25	2.75
Cast No.	1	2	5
Silicon	1.74	2.16	2.75
Sulphur	.093	.080	.090
Manganese	.51	.61	.84
Phosphorus	.65	.72	.55
Total carbon	3.67	3.52	3.16
Graphitic carbon	3.06	2.86	2.56
Combined carbon	.61	.66	.60

English Standard Test Bar Sets:
0.875 inch, 1.20 inches, 2.20 inches Diameter Bars.

Silicon specifications	1.75	2.25	2.75
Cast No.	3	4	6
Silicon	1.74	2.12	2.76
Sulphur	.115	.090	.068
Manganese	.41	.57	.76
Phosphorus	.75	.63	.59
Total carbon	3.49	3.66	3.16
Graphitic carbon	2.99	3.05	2.63
Combined carbon	.50	.61	.53

Table 7

REPORT OF TRANSVERSE TEST—CAST IRON BARS—R. D. WOOD & CO.
TEST DATA OF INDIVIDUAL BARS

Bars 0.875 inches diameter. Supports 18 inches apart

Test No.	Cast No.	Bar No.	Diameter, Inches.	Breaking Strength, Pounds.	Corrected Breaking Strength, Pounds.	Deflection, Inches.	Remarks.
1	3	1	0.87	725	756	0.207	O. K.
2	3	3	.87	825	837	.225	O. K.
5	3	8	.87	735	746	.202	O. K.
6	3	9	.87	825	837	.232	O. K.
8	4	5	.87	795	807	.195	O. K.
10	4	7	.88	790	782	.221	O. K.
Total.....		6	Average breaking strength, 794 pounds; 0.214 inch deflection				
			DEFECTIVE BARS.				
3	3	4	0.87	735	746	0.200	Slightly flawed.
7	4	2	.88	750	743	.195	Slightly flawed.
11	4	8	.88	760	752	.192	Slightly flawed.
13	6	1	.87	655	665	.223	Slightly flawed.
15	6	3	.88	665	659	.215	Slightly flawed.
16	6	6	.86	620	651	.233	Slightly flawed.
4	3	7	0.86	715	750	0.200	Flawed.
9	4	6	.89	720	689	.179	Flawed.
12	4	9	.88	625	616	.163	Flawed.
14	6	2	.87	635	645	.211	Flawed.
17	6	2	.87	675	685	.230	Flawed.
18	6	9	.87	630	639	.216	Flawed.
Bars 1.20 inches diameter.						Supports 18 inches apart	
19	1	1	1.20	1,940	1,940	0.225	O. K.
20	1	2	1.20	1,680	1,680	.169	O. K.
23	1	7	1.20	1,890	1,890	.232	O. K.
25	1	9	1.20	1,755	1,755	.193	O. K.
28	2	6	1.20	1,785	1,785	.184	O. K.
31	2	9	1.19	1,665	1,698	.165	O. K.
32	2	10	1.20	1,700	1,700	.173	O. K.
33	2	11	1.19	1,675	1,709	.160	O. K.
34	2	12	1.20	1,750	1,750	.152	O. K.
35	3	1	1.20	1,855	1,855	.179	O. K.
36	3	2	1.21	2,025	1,985	.200	O. K.
39	3	6	1.20	1,835	1,835	.158	O. K.
43	4	8	1.20	1,775	1,775	.141	O. K.
44	4	5	1.22	1,910	1,815	.165	O. K.
46	4	9	1.20	2,050	2,050	.177	O. K.
47	5	1	1.20	1,665	1,665	.156	O. K.
48	5	2	1.20	1,800	1,800	.160	O. K.
49	5	7	1.20	1,735	1,735	.156	O. K.
51	5	7	1.20	1,805	1,805	.193	O. K.
52	5	8	1.20	1,480	1,480	.134	O. K.
53	5	9	1.20	1,680	1,680	.180	O. K.
54	5	12	1.20	1,640	1,640	.178	O. K.
56	6	3	1.20	1,755	1,755	.210	O. K.
57	6	4	1.20	1,715	1,715	.190	O. K.
58	6	5	1.20	1,660	1,660	.190	O. K.
Total.....		25	Average breaking strength, 1,766 pounds; 0.177 inch deflection				
			DEFECTIVE BARS.				
21	1	4	1.20	1,780	1,780	0.208	Slightly flawed.
24	1	8	1.20	1,715	1,715	.182	Slightly flawed.
27	2	5	1.20	1,570	1,570	.163	Slightly flawed.
30	2	8	1.20	1,630	1,630	.159	Slightly flawed.
37	3	4	1.20	1,625	1,625	.165	Slightly flawed.
41	4	1	1.20	1,735	1,735	.140	Slightly flawed.
45	4	6	1.20	1,740	1,740	.135	Slightly flawed.
50	5	4	1.18	1,530	1,607	.146	Slightly flawed.
55	6	2	1.20	1,540	1,540	.154	Slightly flawed.
60	6	9	1.20	1,710	1,710	.195	Slightly flawed.
22	1	5	1.20	1,485	1,485	0.152	Flawed.
26	1	10	1.20	1,585	1,585	.169	Flawed.
29	2	7	1.20	1,740	1,740	.168	Flawed.
38	3	5	1.20	1,850	1,850	.169	Flawed.
40	3	9	1.20	1,665	1,665	.157	Flawed.
42	4	2	1.20	1,695	1,695	.147	Flawed.
59	6	6	1.20	1,615	1,615	.180	Flawed.

Table 7

(Continued)

Bars, 1.30 inches diameter. Supports 18 inches apart

Test No.	Cast No.	Bar No.	Diameter, Inches.	Breaking Strength, Pounds.	Deflection, Inches.	Remarks.
61	1	1	1.30	2,275	0.258	O. K.
62	1	2	1.30	2,210	.224	O. K.
64	1	6	1.30	2,230	.200	O. K.
66	1	8	1.30	2,385	.174	O. K.
67	1	9	1.30	2,285	.226	O. K.
68	1	10	1.30	2,110	.183	O. K.
69	2	1	1.30	2,330	.234	O. K.
70	2	2	1.30	2,285	.190	O. K.
73	2	6	1.30	2,105	.170	O. K.
76	2	11	1.30	1,890	.130	O. K.
77	5	1	1.30	2,000	.164	O. K.
80	5	5	1.30	1,975	.150	O. K.
84	5	12	1.30	2,050	.165	O. K.

Total..... 13 Average breaking strength, 2,158 pounds; 0.190 inch deflection

DEFECTIVE BARS.

65	1	7	1.30	2,105	0.144	Slightly flawed.
72	2	5	1.30	2,115	.150	Slightly flawed.
78	5	2	1.30	1,945	.150	Slightly flawed.
79	5	3	1.30	2,000	.150	Slightly flawed.
82	5	8	1.30	1,913	.139	Slightly flawed.
83	5	10	1.30	1,840	.140	Slightly flawed.
63	1	5	1.30	1,860	.149	Flawed.
71	2	3	1.30	1,940	.145	Flawed.
74	2	9	1.30	1,845	.150	Flawed.
75	2	10	1.30	1,750	.130	Flawed.
81	5	7	1.30	1,745	.120	Flawed.

Bars 1.40 inches diameter. Supports 18 inches apart

Test No.	Cast No.	Bar No.	Diameter, Inches.	Breaking Strength, Pounds.	Corrected Breaking Strength, Pounds.	Deflection, Inches.	Remarks.
85	1	5	1.40	2,825	2,825	0.184	O. K.
87	1	7	1.40	2,535	2,535	.146	O. K.
88	1	8	1.40	2,695	2,695	.185	O. K.
89	1	9	1.40	2,500	2,500	.156	O. K.
90	1	10	1.40	2,860	2,860	.239	O. K.
91	1	11	1.42	3,000	2,867	.228	O. K.
92	1	12	1.40	2,785	2,785	.223	O. K.
93	2	1	1.40	2,750	2,750	.184	O. K.
94	2	2	1.43	3,010	2,873	.214	O. K.
95	2	3	1.42	3,025	2,891	.190	O. K.
100	2	12	1.40	2,650	2,650	.168	O. K.
101	5	1	1.40	2,575	2,575	.142	O. K.
104	5	7	1.40	2,435	2,435	.127	O. K.
106	5	9	1.40	2,465	2,465	.154	O. K.

Total..... 14 Average breaking strength, 2,693 pounds; 0.181 inch deflection

DEFECTIVE BARS.

98	2	6	1.42	2,730	2,615	0.170	Slightly flawed.
107	5	11	1.40	2,175	2,175	.118	Slightly flawed.
86	1	6	1.40	2,300	2,300	.131	Flawed.
96	2	4	1.40	2,490	2,490	.141	Flawed.
97	2	5	1.40	2,250	2,250	.128	Flawed.
99	2	7	1.40	2,410	2,410	.137	Flawed.
102	5	2	1.40	2,040	2,040	.118	Flawed.
103	5	6	1.40	2,450	2,450	.140	Flawed.
105	5	8	1.40	2,300	2,300	.121	Flawed.

Table 7

(Continued)

Bars 1.5 inches Diameter. Supports 18 inches apart

Test No.	Cast No.	Bar No.	Diameter, Inches.	Breaking Strength, Pounds.	Deflection, Inches.	Remarks.
108	1	1	1.50	3,210	0.170	O. K.
109	1	2	1.50	3,240	.180	O. K.
110	1	3	1.50	3,450	.227	O. K.
111	1	4	1.50	3,350	.196	O. K.
112	1	5	1.50	3,395	.215	O. K.
113	1	6	1.50	3,250	.206	O. K.
114	1	8	1.50	3,200	.183	O. K.
116	2	3	1.50	3,430	.170	O. K.
117	2	4	1.50	3,670	.280	O. K.
118	2	6	1.50	3,455	.179	O. K.
119	2	8	1.50	3,465	.191	O. K.
121	2	10	1.50	3,210	.144	O. K.
122	2	11	1.50	3,645	.170	O. K.
123	2	12	1.50	3,200	.142	O. K.
125	5	4	1.50	3,460	.192	O. K.
127	5	6	1.50	3,250	.183	O. K.
129	5	10	1.50	3,265	.150	O. K.
130	5	11	1.50	3,000	.135	O. K.

Total..... 8 Average breaking strength, 3,341 pounds; 0.180 inch deflection

DEFECTIVE BARS.

115	1	12	1.50	2,735	0.155	Slightly flawed.
128	5	9	1.50	3,240	.144	Slightly flawed.
120	2	9	1.50	2,655	.122	Flawed.
124	5	2	1.50	2,555	.113	Flawed.
126	5	5	1.50	2,905	.138	Flawed.
131	5	12	1.50	2,735	.115	Flawed.

Bars 2.20 inches diameter. Supports 18 inches apart.

Test No.	Cast No.	Bar No.	Diameter, Inches.	Breaking Strength, Pounds.	Corrected Breaking Strength, Pounds.	Deflection, Inches.	Remarks.
132	3	2	2.20	10,040	10,040	0.148	O. K.
133	3	4	2.22	10,600	10,410	.160	O. K.
134	3	5	2.21	10,800	10,650	.158	O. K.
136	3	7	2.22	10,200	10,020	.139	O. K.
137	3	8	2.20	10,525	10,525	.143	O. K.
139	4	5	2.21	10,675	10,530	.112	O. K.
140	4	6	2.22	12,500	12,285	.142	O. K.
141	4	7	2.22	10,400	10,215	.107	O. K.
142	4	8	2.23	12,925	12,410	.148	O. K.
143	4	9	2.21	10,850	10,700	.119	O. K.
144	6	1	2.23	11,100	10,660	.136	O. K.
145	6	3	2.20	11,280	11,280	.149	O. K.
146	6	4	2.22	11,150	10,950	.148	O. K.

Total.. 13 Average breaking strength, 10,821 pounds; average deflection, 0.139 inch

Discussion—Cast Iron Committee's Report

By JOHN SHAW, Sheffield, England.

As a member of the A. F. A. and chairman of the I. B. F. Committee on Physical Tests for Cast Iron, it was with the greatest interest I read the report of the A. F. A. Committee on Gray Iron Castings. Before dealing with the figures and conclusions given it would be as well to lay down two fundamental principles that govern this question.

1. That any cast iron is at its strongest when it contains 0.7 per cent to 1.00 per cent combined carbon. This does not mean that two irons containing say 0.8 per cent combined carbon will be equal in strength, but it does mean that if you cast three bars of say, 1 inch, 2 inch and 4 inch diameter from the same ladle of metal, the one that nearest approaches the 0.9 per cent combined carbon will be the strongest.

2. That it is quite possible to obtain this strongest structure in any one of the above bars by composition and the cooling action on the varying mass. That is, with one composition, casting these three bars 1 inch, 2 inch and 4 inch diameter in dry sand molds cast vertically, it is possible to have 0.9 per cent combined carbon in the 1 inch bar, while the combined carbon in the 4 inch may be down to 0.2 per cent. On the other hand, from another composition the 1 inch bar will contain 3 per cent combined carbon and be white, while the 4 inch will not contain over 0.8 per cent combined carbon.

The above facts will be admitted at once, even by those persistent advocates of the one size bar—Messrs. Moldenke & Wood.

Now let us examine the evidence put before the committee

to help them to come to the conclusions they did, which affects the 5,000 gray iron foundries in North America.

Four returns only are made. There is one point that needs explanation. Are we to understand that the analyses given are the calculated analyses before casting, or the actual analyses in the bar, or is the analysis taken from a separate cast test piece. The report from the Cadillac Motor Co. is by fart the most clear and the resultant tests in each case excellent. Nearly every bar is above the test required, the greatest combined carbon of 0.49 per cent giving the highest result.

The Allis-Chalmers Co. have made no effort to try out either the .875 inch bar or the large 2.2 inch diameter bar, but have contented themselves with the four sizes asked for by the American committee. They have evidently used two stock mixtures for medium castings. The first is evidently about right for all the bars while the second appears to be on the soft side for the larger bars because there is a regular drop from 1.2 diameter bar. No attempt has been made to discriminate between a mixture for castings say ½ inch average thickness and those say 3 inch thick, such as Diesel liners.

The report from the Buffalo Foundry Co. is difficult to understand. Why anyone should put iron containing 1.5 Si. and 3.2 T. C. into castings ½ inch thick and others where no thickness is less than 2 inch is a mystery. The test results are also peculiar. One would naturally expect the .875 bar to fail because it would be too hard, but why the results of the 2.2 diameter bar should be too low is hard to explain, especially when compared with the Cadillac and Wood results with their softer mixture.

Coming now to Messrs. Wood and Moldenke's return, one is surprised that two foundrymen of their experience put forward the three mixtures of iron they tabulate and expect to get comparable results in strength in castings ½ inch thick, and at the other extreme castings 3½ inch thick, say hydraulic cylinders. Can they possibly get a decent strength in the cylinder with any of the three irons set forth? It would appear to a cynical observer that their main object was to have one diameter of test bar, obtain a suitable mixture and let the cast-

ing find its level. In short, make a good test bar. Let us compare the evidence on which we are asked to accept one size of bar.

METAL SUITABLE FOR CASTINGS ½-INCH THICK

	T. C.	G. C.	C. C.	Mn.	S.	Si.	P.
Cadillac Motor	3.42	2.93	0.49	0.69	0.08	2.47	0.17
Buffalo Foundry ...8	3.20	....	....	0.80	0.08	1.5	0.24
Wood	3.49	2.99	0.50	0.41	0.115	1.74	0.75
Wood	3.66	3.05	0.61	0.57	0.09	2.12	0.63
Wood	3.16	2.63	0.53	0.76	0.068	2.76	0.59

That is a variation in Si. of 1.5 to 2.76 per cent.

Take next the medium casting in which no main cross section is less than ¾ or more than 2 inches thick.

	T. C.	G. C.	C. C.	Mn.	S.	Si.	P.
Cadillac Motor	3.61	3.2	0.41	0.71	0.094	2.28	0.21
Allis-Chalmers	3.43	....	....	0.48	0.131	1.43	0.43
Allis-Chalmers	3.48	....	....	0.47	0.093	1.91	0.58
Buffalo Foundry	3.20	....	....	0.80	0.080	1.50	0.24
Wood	3.49	2.99	0.50	0.41	0.115	1.74	0.75
Wood	3.66	3.05	0.61	0.57	0.09	2.12	0.63
Wood	2.16	2.63	0.53	0.76	0.068	2.76	0.59

A variation in silicon of 1.5 to 2.76 per cent.

For castings in which no main cross section is less than 2 inches the following compositions were put forward as suitable:

	T. C.	G. C.	C. C.	Mn.	S.	Si.	P.
Cadillac Motor	3.46	3.02	0.44	0.46	0.079	2.04	0.2
Buffalo Foundry	3.20	....	....	0.80	0.08	1.50	0.24
Wood	3.49	2.99	0.50	0.41	0.115	1.74	0.75
Wood	3.66	3.05	0.61	0.57	0.090	2.12	0.63
Wood	3.16	2.63	0.53	0.76	0.068	2.76	0.59

Now I think a study of the mixtures given above will convince any practical man that at least some of them are not suitable for the thickness of casting they would be required for, judged by the size of the bar they were cast into. We in this country believe that the mixture should suit the casting and not the bar. It is because we find it impossible to do this and use any one size bar that the three sizes of bar were adopted. In fact, in the minds of some members this was not far enough, but practical considerations forbid further sub-divisions.

I have just read through the history of the American bar since the year 1893. I find that man of vision, the late Thos. D. West, was the first to advocate the round bar. He also states in 1897 "All founders should labor to the end of inaugurating a standard system of tests, and for which the writer advocates

round bars having areas equal to one, two and three square inches, the latter for use in hard metal, the former in soft iron."

I could quote name after name who have held this view, and the fact that the Government included a 3 inch bar in their specification, but made the mistake of turning it down to 1.129 inch diameter to meet the testing machines for tensile and so leaving the soft center. Dr. Howe held this view. Prof. Porter stated in October, 1912, "In testing of strength it must be remembered that the purposes of cast iron depend in part upon the thickness of the section and hence that in cases where it is not possible to test the costing itself *the test piece should at least approximate the section of the casting.* Probably three standard sizes of test bars could be selected, to represent the three classes of light, medium and thick castings." The last quotation in this respect is the paper delivered before this year's convention by Mr. Bolton, in which he states that other things being equal, cast iron is at its strongest when the combined carbon is between 0.7 per cent to 1 per cent and that with increased combined carbon its strength falls away rapidly. With the lowering of the combined carbon below the points named its strength falls to a minimum.

Turning now to the mechanical objections, your secretary states the .875 is too small for any accurate results. I think if he will compare these results to the 1.2 size of bar he will find just about the same variation. It must also be remembered that in the Wood results the bar was tested at 18 inch centers and not 12 inch as per specification. It is also stated that the .875 gave 66 per cent bad castings. Well, in this country, we should not have wanted a new size of bar, but a new foreman. The funny thing about it is that a committee[1] on tests took just the same line about the present bar when first introduced by West in 1894. "A lengthy discussion took place between several of the gentlemen present on the points brought out by the report of the Committee. The strongly adverse decision against round test bars, for which so much had been claimed, etc." Table No. 1 showed 55½ per cent bad, No. 3 series showed 43 per cent bad, while all the square bars were perfect, etc. So there is

[1]Western Foundryman Assoc.

still hope you will be able to make a ⅞ round bar 15 inches long without flaws.

A comparison of the deflections on the .875 bar shows no more variation than the 1.2 diameter bar.

"The 2.2 inch bar gave good results and good deflection curves, but the factor of the load required to break them places them out of consideration." So the testing machine is of more importance than the casting. We say scrap the machine and know the strength of the metal best suited for the thick casting. I think it is already proved you cannot get good test bars 1.2 inch diameter and the strongest castings in the thick castings. I will finish with a quotation from Dr. Moldenke, with which we on this side are in complete agreement.

"Primarily the test bar is to show its maker what information can be obtained in regard to the physical quality of the material he has cast. In other words, his product is already complete, but he has to some extent a safeguard which will enable him to ship his work with an easy conscience, or scrap it if not up to requirements. Secondly, the test bar serves as a fund of information, the careful study of which is of great value to the founder in subsequent work. *In both cases just mentioned the test bar should approach the leading dimensions of the work, or better still, be cut directly out of a casting rejected.*"

REPLY:

It is felt that Mr. Shaw has read much more into the committee report than is justified. The recommendation of the 1.2 bar does not necessarily imply that this is the bar which is to be used by the American member of the International Test Bar Committee. This report outlined the work of the members of the committee on test bars, which were cast separately and of different diameters to ascertain if any of these test bars, which might be cast apart from castings, would serve the purpose of recommending to the Board of Directors as the best. By a canvassed vote it was decided that the 1.2 inch diameter round by 18 inches long test bars should be those suggested. It was specifically stated that this test bar is not to be representative of any casting poured from a heat from which the test bar

was also poured. Rather, this bar was to be only indicative of the condition of the metal in the ladle, from which the bar was poured.

The acceptance of this bar by the American Foundrymen's Association purely indicates its idea of what might prove to be the best method of testing cast iron, according to the needs of the American foundryman.

If practical, it is felt that American foundymen would welcome a bar for every section of metal, but unfortunately this is not practical. Even the British have compromised on three bars, while we go a little further and make only one. It is hard to conceive of a bar cast separately from a casting representing all parts of the casting. Even if a bar should be made the same size as the average section of the casting, would it represent all sections of the casting? Also while castings might have the same thickness of section due to the variation in the mass of the molds, some would be cooled quicker than others and the metal quality would also vary.

If we are to have the test bars represent the metal in the casting, what an infinite variety of bars we would have and what variations in rates of cooling would be necessary to make them correspond to the cooling rates of the castings.

Melting Steel in a Cupola

By J. Grennan, Ann Arbor, Mich.

Introduction

In the foundry laboratory at the University of Michigan, the cupola has a series of holes cut through the side so that the process of melting can be observed. A paper was presented at the Cleveland meeting of the American Foundrymen's Association, describing some observations made through these holes. Further observations have been made that may be of interest to foundrymen.

Equipment

The engineering shop laboratories at the University of Michigan moved into the new East engineering building during the past year. The old foundry was closed at the beginning of the Christmas vacation and the new one opened in January. The old cupola and the new one are illustrated in Fig. 1. The observations cover melting both in the old and new cupolas. The old cupola was equipped with an American Blower Company's Type P., No. 5 blower, run at about 2,400 R. P. M. delivering about 1,500 to 1,600 cubic feet of air per minute. The new cupola is a No. 3 Whiting, equipped with a No. 3 Roots blower. The blower is driven by a variable speed motor, which makes it possible to keep the blower speed constant at any speed within the range of the motor. The blower was run at the rate of about 270 R. P. M. which would deliver between 1,900 and 2,000 cubic feet of air per minute, according to the Roots Company's figures.

Acknowledgment is made of the assistance given by the staffs of the Engineering Shop laboratories and the Chemical Engineering Department of the University of Michigan. H. I. Dixon, a senior mechanical engineering student, must be given credit for doing a large amount of routine work. He registered as a student in advanced foundry work and helped carry on the experiments conducted in the new cupola.

Object of Experiments

It was the object of these experiments to determine how steel melts in a cupola and to compare the melting of steel with that of pig iron and scrap cast iron.

Steel absorbs carbon in the melting process. To determine how much, and where this carbon absorption occurs, pieces of

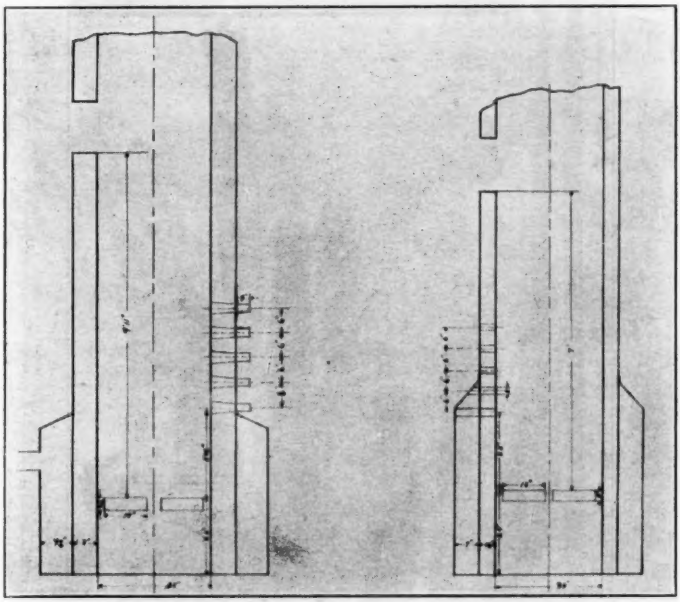

FIG. 1—NEW AND OLD CUPOLA USED IN INVESTIGATION.

steel were removed from the cupola and studied under the microscope. To determine the atmosphere in which the melting occurred, gas samples were taken and analyzed. Comparisons as to size of pieces melted were made, and the nature of melting was observed.

Absorption of Carbon

Fig. 2 shows pieces that were put in as part of the charges

and removed from the holes in the side of the cupola. Fig. 3 shows pieces that were taken from the drop.

The photomicrographs, Figs. 4 to 8, show varying degrees of carbon absorption. Figs. 4, 5, and 6 are photomicrographs of a piece of steel (2, Fig. 2) charged on top of the coke and taken

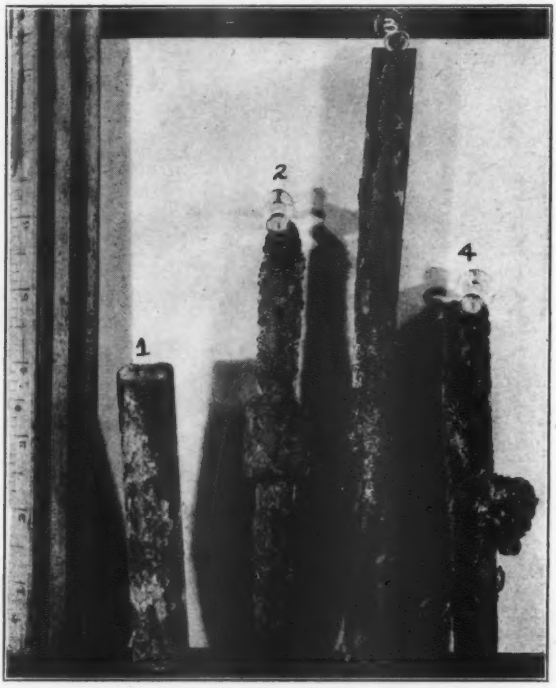

FIG 2—PIECES OF STEEL REMOVED FROM CUPOLA DURING MELTING OPERATION

from hole No. 2 in the old cupola twenty minutes after the blast was turned on. The specimen was examined where the piece was half melted away. Fig. 4 shows the outside, and is composed of pearlite and cementite. The uneven edge on the right is the outside of the piece. Fig. 5 shows another spot on the

same specimen where the carbon absorption was not so deep. From right to left there is considerable difference. At the right the structure is composed of pearlite and cementite and represents the outside of the piece. At the left the structure is shown as pearlite and ferrite with a band of pearlite between it and the right-hand side. Fig. 6 shows the center of the piece where no carbon had been absorbed.

Fig. 7 is a photomicrograph of a piece of steel (3, Fig. 2) taken from hole No. 3 in the old cupola fifteen minutes after the

FIG. 3—PIECES OF STEEL REMOVED FROM CUPOLA DROP

blast. The piece showed slight signs of having started to melt in one or two spots. On the right of Fig. 7, the structure is nearly all pearlite and shows the carbon absorption at the outside of the piece.

Fig. 8 is a photomicrograph of a piece of steel taken from hole No. 5 in the old cupola, twenty minutes after the blast was

FIG. 4—PHOTO MICROGRAPH OF PIECE OF STEEL REMOVED FROM HOLE NO. 2. ETCHED WITH PICRIC ACID. X100. OUTSIDE SECTION

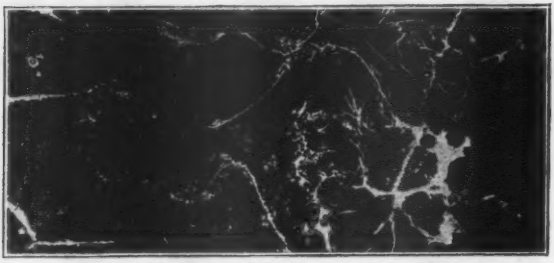

FIG. 5—SHOWS ANOTHER SPOT ON THE SAME SPECIMEN AS FIG. 4 WHERE THE CARBON ABSORPTION WAS NOT SO DEEP, ETCHED WITH PICRIC ACID. X100

FIG 6—SAME SPECIMEN AS FIG. 4, BUT FROM CENTER SECTION OF PIECE

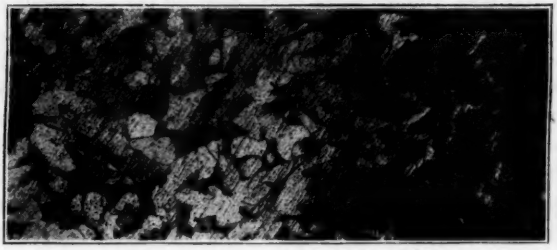

FIG. 7—PHOTO MICROGRAPH OF PIECE OF STEEL TAKEN FROM HOLE NO. 3. ETCHED WITH PICRIC ACID. X100

FIG. 8—PHOTO MICROGRAPH OF PIECE OF STEEL TAKEN FROM HOLE NO. 5, IN OLD CUPOLA. PICRIC ACID ETCH. X100

on. It had started to melt at the spot where the photomicrograph was taken. On the right is shown the irregular outline of the outside of the piece. The structure on the left is almost that of the original low carbon steel. The condition shown is one where carbon absorption had occurred, and there had been a reduction of this carbon by oxidization.

Obtaining Samples for Photomicrographs

The method first used to get specimens for photomicrographs consisted of placing small pieces of steel on top of the coke of each charge and then trying to remove them from the peep holes in the side of the cupola. This proved a difficult task.

Several types of tongs and devices were tried, but a plain

straight rod with a short right angle bent on the end proved the most successful. In the second method, the cupola was charged with more metal than was required and the bottom dropped before melting was completed. Bars were also introduced through small holes in the peep hole covers and withdrawn when partly melted.

The carbon absorbed by the pieces of railroad rails, shown in Fig. 3, was similar to that shown in Figs. 4 and 5 and is typical of the carbon absorption found where the size of the pieces was appreciably reduced by melting. The pieces in Fig. 3 which showed only slight signs of having started to melt showed carbon absorption similar to that shown in Figs. 7 and 8. Signs of oxidation as shown in Fig. 8 were common in those pieces where signs of melting were slight. In all, about twenty samples were examined under the microscope. The carbon absorption was not marked until signs of melting were shown on the piece. The photomicrographs shown cover all the conditions found where signs of melting were shown.

Watching Steel Melt

Size of Steel Compared to Pig Iron

An experiment was conducted in which the first charges into the cupola were made up of steel automobile wheel rims and pig iron. The steel was charged next to the coke with the pig iron on top. The first iron tapped from the cupola was hard. The following is the make-up of each of the first five charges of one heat and the analysis of the first and third tap.

164 pounds—1.55 per cent silicon—pig iron.[2]
202 pounds—4.14 per cent silicon—pig iron.
122 pounds—0.028 per cent silicon—steel wheel rims.
Analysis first tap—1.09 per cent silicon.[3]
Analysis third tap—1.98 per cent silicon.

The bed charge of coke was 28 to 30 inches above the tuyeres. The iron charges were 488 pounds with 75 pounds of coke between charges.

The steel was observed to melt as high as hole No. 5, 46

[2]Combined carbon, 0.58 per cent.
[3]Analysis by G. W. Whitney.

inches above the tuyeres. The steel wheel rims melted completely from the first charge and considerably from the second before there was any rapid melting of the pig iron in the first charge.

After the test referred to above, the cupola was run as follows: The bed charge of coke was 28 to 30 inches above the tuyeres. There were 75 pounds of coke between charges. The iron charges consisted of 700 pounds of pig iron and scrap cast iron, the pig iron being 50 per cent of the charge. Pieces of steel of varying cross section made up 10 per cent of the charge, the remainder being pig and scrap cast iron. The automobile wheel rims, which were 3/16 of an inch thick, were the thinnest sections used, while the heavier pieces ran up to one and one-half inch across section. There was considerable variation in the melting condition but in these observations it was found that steel up to one and one-half inches thick, when charged on top of the pig iron, would melt as soon as a piece of pig iron four inches thick.

Slag on Steel and Cast Iron

The nature of the slag was quite different on the steel from that on the pig and cast iron. The slag which formed on steel was quite liquid and ran off freely. The slag which formed on pig iron and cast scrap was highly viscous and instead of running off remained on the iron so that the cast iron and pig iron melted inside an envelope of slag.

Cupola Gases

Gas samples were taken from the cupolas from holes No. 1 and No. 3. Details of the gas sampler are shown in Fig. 9. The gas was caught under water and analyzed in an Orsat apparatus. Some gas was taken from the old cupola in some preliminary tests. The heats were short, and the results were similar to those found at the beginning of the heats in the new cupola. The amount of CO_2 near the lining was high, there being a large difference between the gas at the lining and near the center of the cupola.

The charging of the new cupola was as follows: The coke bed was about 30 inches above the top of the tuyeres. The iron charges were 600 pounds each. There were 75 pounds

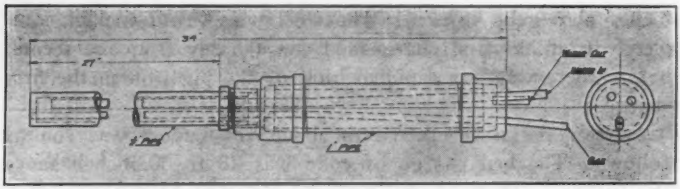

FIG. 9—DETAILS OF GAS SAMPLER

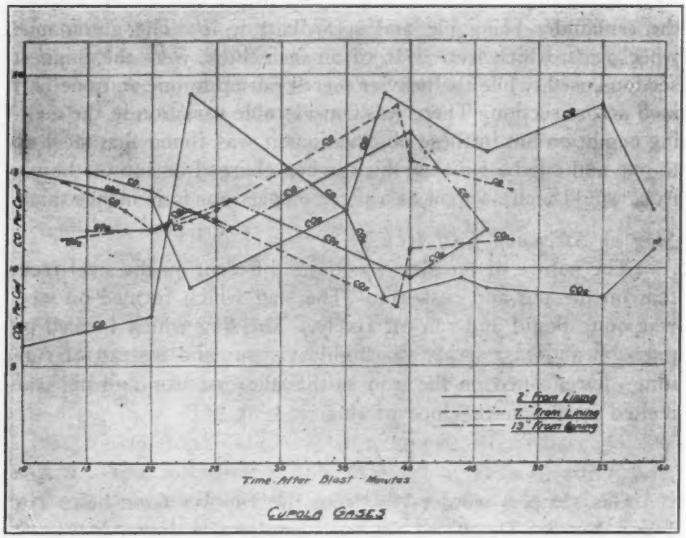

FIG. 10—CHART SHOWING ANALYSIS OF GAS TAKEN FROM CUPOLA AT VARIOUS TIMES AFTER BLAST WAS TURNED ON

of coke between the iron charges. Twelve pounds of lime stone were placed on top of each charge of coke. The melting was observed to occur as high as hole No. 5 where thin pieces melted near the lining to as low as hole No. 1 where the remains of large pieces melted.

Considerable difficulty was experienced in getting samples

of gas in the preliminary tests, so it was decided not to try to get gas from all holes but to get it at two first and compare the results.

Table 1 gives the gas analysis arranged in the order of the time the samples were taken after the blast was turned on. The graph, Fig. 10, makes it a little easier to visualize the relation of CO_2 to CO in the gases taken from hole No. 1.

The gases analyses given in the table were from the gases from the new cupola. It will be noticed by referring to the graph that the ratio of CO_2 to CO was high at the lining of the cupola at the beginning of the heat at hole No. 1, and that

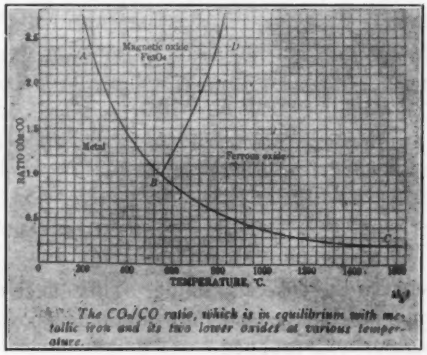

FIG. 11—THE CO^2/CO RATIO WHICH IS IN EQUILIBRIUM WITH METALLIC IRON AND ITS TWO LOWER OXIDES AT VARIOUS TEMPERATURES

at the end of the heat there was a tendency for the CO_2 to CO ratio to increase.

At the beginning of a heat, the coke was full size, as charged, with no slag present. This allowed a freer passage for the blast through the coke and along the lining than existed later. As the coke burned, the size was reduced and the blast was more evenly distributed through the coke. The lining at the hottest point softened, and some of it slipped down and became plastic so the coke bedded into the soft lining, cutting off

Table 1

Cupola Gases.

No.	Minutes After Blast	Hole No.		Inches from Lining		Per Cent CO_2	Per Cent O_2	Per Cent CO	Heat No.
1	10	1	2			15	.0	6	18
2	20	1	2			13.5	.0	7.5	13
3	23	1	2			9	.0	19	17
4	35	1	2			13	.0	13	19
5	38	1	2			8.5	.0	19	15
6	44	1	2			9.5	.0	16.5	16
7	46	1	2			9	.2*	16	14
8	55	1	2			8.5	.0	18.5	15
9	59	1	2			11	.0	13	14
10	13	1		8		11.5	.0	14.5	18
11	18	1		10		12	.0	13	19
12	20	1		6		12	.0	12	13
13	23	1		8		13	.0	12.5	19
14	25	1		7		12.5	.0	13	19
15	39	1		6		8	.0	18.4	15
16	40	1		5		11	.0	15.5	19
17	48	1		8		11.5	.2*	14	14
18	15	1			13	12	.0	15	18
19	20	1			13	12	.0	14	14
20	26	1			11	13.5	.0	12	19
21	40	1			13	9.5	.0	17	15
22	46	1			13	12	.4*	12	14
23	12	3	2			14	.3*	10.5	19
24	17	3	2			13	.0	12.5	18
25	26	3	2			9	.4*	18	17
26	34	3	2			11	.0	14	17
27	13	3		6		12	.2*	14	19
28	18	3		10		10	.0	16.5	18
29	20	3		10		13	.0	13	19
30	26	3		8		9	.0	18	17
31	28	3		6		12.5	.0	13	19
32	57	3		8		10.75	.0	14.7	14
33	19	3			13	11	.0	15	18

*The small amount of O_2 present in some samples may have been taken from the water, or it may be due to an error in testing.

the space between the coke and lining. This effect was observed by examining the coke bedded into the lining above the tuyeres after the bottom was dropped.

The result of these changes was a change in the CO_2-CO ratio near the lining to a ratio similar to that existing in the rest of the cupola. This ratio of CO_2-CO was fairly constant until the reduced resistance near the end of the heat allowed a freer passage of gas through the stock and the ratio CO_2-CO increased. The change in blast pressure from an average of about seven ounces at the beginning of each heat to about nine ounces, twenty minutes later, showed a change in the condition of the bed.

There was not much change in the gases as they passed from hole No. 1 to hole No. 3. The CO_2 content along the lining was high at the beginning of the heat as shown by the 14 per cent in the sample taken 12 minutes after the blast was

turned on. There was less difference in the ratio CO_2-CO at hole No. 3 than hole No. 1, which was probably due to the better mixing of the gases due to passing through more stock.

Oxidation in the Cupola

CO_2 an Oxidizing Gas

There is no doubt from the observations made that with no free oxygen present, steel will oxidize readily in a cupola. The equilibrium diagram, Fig. 11, shows the CO_2-CO relation which is in equilibrium with metallic iron[4] and its two lower oxides at various temperatures. From the diagram, it will be seen that as soon as the stock reaches a temperature at which it will oxidize readily, the atmosphere in the cupola is an oxidizing one.

The oxidation of the steel may be reduced or minimized by the selection of stock. A preference[5] has been shown for steel of fairly good section, such as rails, medium forgings or heavy boiler plate clippings. Drop forging flushings are cheaper but are light and oxidize more readily. The light steel heats faster than the heavier steel and is much closer to the temperature of the gases by which it is surrounded as it descends in the cupola. The light steel reaches an oxidizing temperature in an atmosphere that is not hot enough to melt the steel. The heavier steel descends farther in the cupola before reaching an oxidizing heat and is much nearer the highest temperature zone before it begins to oxidize. As the heavier steel offers less surface to oxidize and is in a hotter place in the cupola, it would melt in relatively a shorter time than the light steel.

There is oxidation and carburization going on in the cupola at the same time. The carburization is not active until the steel is very close to melting. The carbon content of steel rails for railroads averages around 60 to 70 points as compared to 15 to 35 in the common machinery and structural steels.

It is possible that with rail steel the carbon may be oxidized and thus take up oxygen that would otherwise oxidize the iron.

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[4]P. H. Royster, T. L. Joseph and S. P. Kenney, The Blast Furnace and Steel Plant, January, 1924, pp. 35, 36.

[5]Notes on Gray Iron for Automotive Castings, H. B. Swan, Vol. 31, Transactions A. F. A., 1924, p. 83

Fig. 8 shows oxidation of carbon after carburization has occurred.

Slag on Steel and Cast Iron

The slag on the steel was observed to flow off freely while the slag on the pig iron and scrap cast iron was highly viscous and remained on the stock. The iron oxide forms a low viscosity slag[6] with the ash which is blown up from the burning coke against the steel. This low viscosity slag flows freely at a lower temperature than the steel melts. As the slag flows off, fresh surfaces are exposed for further oxidation.

The cast scrap and pig iron contain silicon, some of which is oxidized in the cupola. This silica would tend to increase the viscosity of the slag.[6] The slag thus formed having a high viscosity, remains on the scrap cast iron and pig iron while it melts.

Melting of Steel

There has been considerable discussion and conjecture as to how steel melts in a cupola. Colonel Jamie Coll, reviewing the question of cupola reactions in a paper at the International Congress of Foundries at Paris, in September, 1923, summed up the experiments of several and concluded that steel melted as steel. These experiments confirm his conclusion. The condition, shown in photomicrographs 4, 5 and 6, is typical of rapidly melting steel. The carbon content was estimated to be between 1.25 per cent and 1.35 per cent in these photomicrographs. In no case did the carbon appear to be higher than is shown in these pictures. It seems reasonable that steel reaches at least one per cent carbon before melting. Dr. Moldenke's experiment,[7] in which he determined the melting point of steel in a cupola as 2,450 degrees Fahr., would indicate that the steel absorbed carbon, thus becoming a high carbon steel.

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[6]"How Slag Affects Cupola Operations," by J. W. Bolton, *The Foundry*, Sept. 1, 1921, p. 681.

[7]Principles of Iron Founding, R. Moldenke, McGraw-Hill, New York, 1917, p. 101.

Comparison of Melting of Steel and Pig Iron

In melting, steel absorbs carbon and as the penetration is slight, the outside of the piece has a lower melting point than the rest of the piece. The outside melts and runs off. The steel is observed to melt much as ice melts to water. Pig iron melts in quite another way. The melting of pig iron can be compared to the melting of a piece of brick ice cream in a warm room. The pig iron can be seen to become soft as ice cream softens. As this softening occurs, the outside melts. Projecting corners may melt away completely before the heavier center begins to soften. Pieces of pig iron partly melted and greatly reduced in size are common in the dropped metal.

Sizes of Pieces

The sizes of pieces, or rather the cross section and shape, have considerable influence on the melting of scrap iron as well as steel. Foundrymen, who would nor hesitate to charge a heavy piece of pig iron or scrap iron, are very careful not to charge steel that would melt more readily than the pig iron or scrap referred to.

There are two factors in the melting process. They are the size of stock, and the melting point of the material. The temperature in the cupola is so much higher than the melting point of pig iron and steel that the absorption of heat by the piece being melted, is of more importance than the abstract melting point of the material Steel was seen to melt as high in the cupola as the lightest cast iron. This does not mean that steel melts as readily as cast iron but a consideration of conditions under which the steel melted 46 inches above the tuyeres will bring out the point desired. The charge consisted of two-thirds pig iron and one-third steel automobile wheel rims by weight, but in terms of space occupied, the pig iron was about one-third the charge, and the steel two-thirds. The irregular shape of the steel made it impossible to pack it closely. The result was that the steel offered a great deal more surface to a much larger volume of gas for the absorption of heat and melted much more readily than the lower fusing point pig iron.

Location of Steel in Charge

The thickness of the steel will determine its location in the charge. If the thickness is greater than one and one-half inches, the steel should be charged on the coke. If less than one and one-half inches thick, it should be charged on top of the pig iron. Steel one and one-half inches thick will melt as soon as pig iron four inches thick when the steel is charged on top of the pig iron. The question of contact with coke to aid the absorption of carbon is of no importance. The absorption of carbon is from the gas. Pieces examined were carburized on all surfaces, showing they were carburized by the gas. If contact with the coke was necessary for the absorption of carbon, the spots that touched the coke would be the only places carburized.

Shape of Stock

As has been shown in the case of the wheel rims, the irregular shaped stock offers the larger surface to absorb heat from the hot gases. Irregular surfaces on steel are desirable. Railroad rails make very desirable steel stock because of their shape. It is possible for the hot gases almost completely to surround the rails, the contact with other pieces being very slight. Flat plates which may lie one on top of another, will not allow space for the hot gases between them. The shapes referred to also apply to cast iron and pig iron. Any shape that allows close packing of the stock prevents free passage of the gas around the stock. Pig iron manufacturers would do well to make their pigs smaller and make a groove the long way, similar to the one across the center. The present pigs, with an almost semi-circular cross section, offer the minimum surface possible for the absorption of heat from the hot gases.

Conclusions

Stock Charged

It seems reasonable that heavier steel may be used as part of the cupola charges than has been generally used. The oxidation of the steel may be somewhat reduced by using the

heavy steel. A point to be stressed is care in getting uniform conditions,[8] in making up the several charges that go to make up a heat. The averaging of the size of materials is about as essential as the averaging of the chemical composition.

High Bed

The change in conditions which were observed to occur during the first of a heat, makes a high coke bed advisable. A bed charge of coke which reaches 30 inches above the tuyeres is high when compared with average practice.

The lack of any large amount of definite information properly coordinated in regard to cupola melting makes the cupola an attractive field for investigation. Foundry literature is rich in opinions as to what occurs in the cupola but concise records of experiments determining actual conditions are not so abundant.

The study of the materials used in the cupola produced remarkable results. It is probable that as careful a study of the process would also improve the product.

Discussion—Melting Steel in Cupola

By S. J. Felton, Cincinnati, Ohio

Mr. Grennan is to be highly commended for the epochal data he is obtaining on what takes place in the cupola. There can be no questioning of such scientific as well as practical observations, but there might be room for discussion on some of the deductions from the tests. For instance, did steel melt as steel in these experiments. On the iron-carbon equilibrium diagram a 1.30 per cent carbon steel starts to melt at about 2,250 degrees Fahr., and is completely melted at about 2,550 degrees Fahr.

Although the conception of the mechanism of melting is somewhat complicated, in the cupola, by the fact that some of the molten drops are free to fall instead of remaining in equi-

[8] See Principles of Iron Founding, R. Moldenke, McGraw-Hill, New York, 1917, pp. 397-398.

librium with austenite, it would still be expected that the metal should go through a pasty stage in the melting process. The fact that steel was observed to melt as "ice melts to water," indicates that the melting temperature was constant, or nearly so. It is entirely reasonable to assume that the steel melted at about 2,250 degrees Fahr. represented by a horizontal (or nearly horizontal) line on the iron-carbon diagram, the carburizing influences causing the molten metal formed, to contain about 3.0 per cent carbon. That is, the micrographs of 1.25 to 1.30 steel probably show the solid metal which was in equilibrium with molten drops containing about 3.00 per cent carbon.

Under the cupola conditions so far used by Mr. Grennan, the melting-points or ranges of the constituents of a charge seem to have varied less than the extremes that might have been anticipated; therefore the effect of size and shape is predominate. There is still a possibility that under different cupola conditions, possibly with free oxygen existing, that a low carbon steel will melt at nearer 2,700 degrees Fahr. In such a case, regardless of size, the solid steel must necessarily get lower than 46 inches above the tuyeres before melting, according to the cupola temperatures recorded by Mr. Grennan.

The results of these tests indicate that the effect of the size and shape of the individual pieces of the charge is greater than might have been expected, however I have also had some occasion to notice this effect. For instance, I have found that it is difficult to obtain the highest tapping temperatures when anything heavier than 50-pound chill pigs (or fragments) are used, in a 48-inch cupola[1]. Presumably heavier pigs get so low in the stack, before melting is completed, that there is insufficient superheating of the molten drops because of the shorter distance they fall. This is further emphasized by the lower melting-point of most chill pig.

A variation of two or three hundred degrees which is supposed might exist in the melting-point (or range) of the different constituents of a charge, represents a great deal more than the allowable variation in tapping temperatures. Therefore, I still believe that some compensation arrangement takes place in

[1]Heavier chill pig iron broken in two is usually all right.

the stack. If a piece of light gray-iron scrap melts 46 inch above the tuyeres, a piece of white iron scrap of the same size and shape should melt further up, other conditions being equal. The same idea applies to high melting point sand cast pig as against low melting point chill pig.

It would seem interesting to run further tests involving different melting speeds and varying stack conditions, with a check on tapping temperatures and oxidation losses. In order to compare with commercial cupola practice, some metal should be charged after the blast is started. I suggest that a volume-meter would prove very beneficial in this work, so that the CO_2 zone could be regulated more effectively.

Mr. Grennan should be congratulated on his unique method of pursuing cupola research, and we should expect many other interesting papers from him in the future.

AUTHOR'S REPLY—The reference that Mr. Felton makes to the iron carbon diagram, and his argument that a steel which

FIG. 1—PHOTOMICROGRAPH SHOWING A DROP OF MOLTEN STEEL AND CAST IRON. THE UNION OF THE STEEL AND CAST IRON CAN BE CLEARLY SEEN IN THE LOWER HALF OF THE ILLUSTRATION. ETCH—PICRIC ACID. 100 x.—(PHOTOMICROGRAPH BY H. I. DIXSON)

had absorbed 1.30 per cent carbon when it started to melt would be a 3 per cent carbon cast iron when completely molten, is very interesting and should be carefully considered.

On a piece of railroad rail taken from the bottom drop, there was found a drop of metal that appeared to be about to drop from the rail. The dropping of the bottom must have occurred just at the time to check the drop and freeze it to the rail. Under the microscope the drop proved to be a hybrid with a steel outside and cast iron center. The weight was only one gram and no one cared to try for a chemical analysis, so the piece was filed away. Mr. Felton's discussion made a partial analysis desirable and an analysis for silicon gave 1.11 per cent.[1] The presence of so much silicon is proof that the center was cast iron, when charged. The photomicrographs show a perfect union between the steel and cast iron, yet the line between the two is quite distinct. This can be seen in Fig. 1 on page 465.

It would seem reasonable to believe that the drop, in order to flow, was molten and that the absorption of carbon by the steel was about the same as shown in the paper.

[1]Analysis by R. Schneedewind.

Testing Iron to Control the Properties of Castings

By G. W. Gilderman, Mishawaka, Ind.

Perhaps in no other branch of industry does the human element play so prominent a part as in the foundry and this element must be taken in constant consideration while drawing conclusions from any test or from any series of tests. Tests of metal are made in the foundry for two reasons: First for the benefit of the customer to assure him that the castings are poured from metal that conforms to definite specifications; second for the benefit of the foundryman himself to keep a check on his practice. Any attempt to provide a suitable test that will cover the varied lines of castings manufactured by foundries throughout the country, presents a rather difficult problem. Foundrymen in general select their pig iron on a chemical analysis basis, but they demand something further in the form of physical tests to determine the strength, hardness, grain, shrinkage and other properties of the casting.

Careful daily comparison of chemical and physical tests will be found of great assistance when the foundryman is confronted with difficult specifications. Intelligent consideration must be given to the difference in size and shape of the test piece compared with the proposed casting. Up to the present no one test or series of tests has been developed to indicate the exact condition of the casting from the standpoint either of its chemical or physical properties. Each test has a definite value, but additions or deductions must be made to the result to indicate what may be expected in the casting poured from the same iron.

Factors That Tend to Make Test Bars Unreliable

Among the many factors that tend to make test bars unreliable, probably the most important is the difficulty experienced in attempting to control the cupola mixtures and the manner in which they are placed in the cupola. Many things happen in the cupola that are not listed on the program. One of the most common sources of trouble may be traced to a variation in the size of the scrap iron. The men making the charges as a rule are somewhat unreliable. At times all the light scrap will be placed in one charge with several pieces of heavy scrap in another. The heavy scrap tends to settle in the coke bed and at times two or three charges will melt down before the heavy pieces are entirely fluid. On the other hand, the light scrap sometimes will melt before the pig iron in the same charge with the result that one tap will contain too light a percentage of scrap and another, perhaps immediately following, will have an excess.

Variation in Casting Qualities

An example of this was encountered recently. A floor of 12 pulleys was poured during the same heat. Ten of these pulleys were sound while on two, the arms had pulled apart. An analysis of one of the perfect pulleys showed the following: Silicon, 2.18 per cent and sulphur, 0.085 per cent. One of the defective pulleys on analysis showed silicon 1.85 per cent and sulphur 0.113 per cent. The excess of sulpur and deficiency in silicon will be noted in the defective sample. A test bar was taken from the second tap, one from the middle of the heat and the third from the last of the heat. All three bars proved satisfactory and all showed silicon in the vicinity of 2.15 per cent. A chill test taken from the middle of the heat, poured from medium hot iron, showed a very fine white line across the bottom of the bar. However, the test of the bar compared very favorably with the average from the daily practice in this foundry.

It will seem from above that the two defective pulleys must have been cast from clear scrap, and as none of the test pieces happened to be taken from this particular ladle, had this iron been poured into some casting of a more rigid design, this hardness might not have been discovered until the casting was

machined. Yet four tests taken from different parts of this heat were entirely satisfactory.

A round plate casting of the following dimensions, 8¾-inch diameter, 3 inches thick with a solid hub on one side 3¼ inches in diameter and 6¾ inches long, was cast from the same ladle with a 1¼ inch test bar. Both the casting and test bar were molded in green sand and after pouring were allowed to remain in the mold until cold. The hub projecting from the casting then was broken off and drillings taken from the center of the plate analyzed as follows: silicon 1.91, manganese 0.76, phosphorus 0.530, sulphur 0.088, and combined carbon 0.47.

Drillings taken from the center of the test bar showed practically the same analysis with the exception of combined carbon which was .54. A transverse breaking test of this bar gave 2,640 pounds. It would be unsafe to figure the casting on the same basis as the test bar. While the outer shell of the casting in all probability would compare favorably with the test bar in strength, the inner section would be weaker due to the difference in cooling and the consequent difference in the percentage of combined carbon.

Chill Tests Criticized

In the author's opinion a chill test is not always reliable. In one instance, two bars were cast in iron molds 5 inches thick, 6 inches wide and 16½ inches long. The bars were 12½ inches long and with an average of 2 inches square cross section. It will be seen that the chill provided 3 inches of metal beneath the bar and 2 inches entirely surrounding it with the exception of the top, which was open. The first bar was poured at a very low temperature, and showed a white line across the bottom 3/64 inch. The sides showed no white whatsoever with the exception of the bottom corners, where the chill was about ⅛ inch deep. Drillings taken from the top of this bar showed an analysis of silicon 1.84, manganese 0.72, phosphorus 0.531, sulphur 0.078, and combined carbon 0.47.

This bar showed no gradual tapering off from white to gray but a sharp demarcation existed between the chilled portion and the ordinary gray section.

The second bar was poured at a very high temperature and showed a white line across the foot 5/64 inch deep. This line also extended up the sides of the bar for about 5/8 inch. The chill at the lower corner was about 1/4 inch deep. This bar showed a gradual tapering from white to gray and drillings taken in the same manner and from approximately the same location in the bar gave an analysis of silicon 1.82, manganese 0.56, phosphorus 0.497, sulphur 0.091, and combined carbon 0.60.

It will be noted that the second bar showed a much deeper chill than the first. The silicon being practically the same, could not have caused this variation. While the manganese is higher in the first than in the second bar, the sulphur is reversed and is higher in the second than in the first bar. Judging from the analysis, it is the opinion of the writer that had these two bars been poured of iron of the same temperature they would have shown approximately the same chilled conditions.

Test Bars Do Not Tell Exact Properties of Iron in Castings

This furnishes an indication of the unreliability of common tests unless all of the variations encountered are carefully noted. It also supports the contention that any test made in this manner is not strictly a measure of the properties of the casting but rather a test of the iron when it is poured into the casting. Foundrymen often develop some simple test that will give information adaptable to his one peculiar line of work. The writer considers the best guide for general use is the 1¼-inch round test bar poured in a dry sand mold. As it is rather difficult to obtain a true tensile test, the transverse generally is used, placing the bar on supports 12 inches apart. The load is applied at the center at a speed to produce 0.10 inch deflection in about 30 seconds. Drillings may be taken from the broken bar for a comparison of chemical analysis and for a consideration of the effect of the chemical analysis upon grain structure, strength and other physical characteristics. A careful study of the grain structure compared with the analysis at times will assist in eliminating segregation or shrinkage. Further, the bar may be placed in the lathe and the end turned to determine the degree of hardness and resistance to machining.

Precaution Needed in Making Test Bars

In making the mold for the 1¼-inch test bar, great care should be exercised in ramming, in order that the bars may be as near the same diameter as possible each day. Perhaps the safest plan is to make the mold on a jolt rammer. Decide upon the number of jolts necessary to secure the proper density, and make this a daily practice. Even with this precaution, there will be at times considerable variation in the breaking point of the different bars. The table on this page is part of a foundry record where daily tests are made, and does not include any bars which contain a flaw of any kind. Bar No. 1 was cast at the beginning of the heat, bar No. 2 at the middle of the heat, and bar No. 3 at the last of the heat.

Table 1

	Chemical Analysis				*Bar Number*		
Heat No.	Silicon	Sulphur	Phosphorus	Manganese	1	2	3
					Transverse Strength		
1*	1.61	.095	.44	.70	3660	3590	3640
2	1.90	.090	.46	.60	3050	2940	2925
3	2.10	.089	.58	.63	2600	2795	2764
4	2.16	.087	.60	.71	2415	2700	2740
5	2.25	.081	.57	.67	2540	2440	2800
6	2.42	.082	.61	.61	2400	2340	2310

*20 per cent steel.

Hardness Testing

As a test for hardness the scleroscope and Brinell machines are both used. The Brinell test is more easy to read and consequently more accurate for practical use. Generally speaking where hardness is required, the casting is subjected to great wear and a certain degree of hardness is specified to insure a certain amount of wear. When this is true, it would seem the Brinell machine is to be preferred over the scleroscope, for the reason that with the Brinell, a certain pressure displaces a certain amount of metal. This is practically what happens when the casting is put into use.

The Brinell test is used to good advantage on castings for internal combustion engines in determining the degree of hardness of cylinders, pistons, piston rings, and other parts subject to wear. Of course, it also may be used to advantage on any casting where the degree of hardness is confined to narrow limits. Best results are obtained by taking two or three castings from each hundred after they have been machined and applying the test directly.

Discussion—Testing Iron to Control the Properties of Castings

CHAIRMAN A. B. ROOT: A problem of the tests and the uses made of the test bars is one of such common practice amongst us that there may be interesting problems which you have had and which you would like to mention, which would be of benefit to the others in connection with their experience in the use of the test bar. The points, as brought out by Mr. Bolton in his paper, with reference to the different size of bars, between the diameters of the bars, and the results obtained, have their effect equally on tensile and transverse strength, as well as on the hardness of tests as referred to by Mr. Gilderman. There may be a question of interest, on the relation between the hardness and the amount of wear, as to what extent does this represent the true characteristics of the metal, and to what extent does it indicate its possibilities for this service, whether there are other elements equally as important or more so than Brinell hardness, as indicated by such tests. If there are any who have such ideas in mind or others, we would be very glad to hear them.

G. W. GILDERMAN: I brought out one thing in my paper, as to the tapering off from white to the gray iron, that it was so abrupt. I don't know what caused it and would like to know if somebody here can explain it?

J. T. MACKENZIE: The thing that strikes me about Mr. Gilderman's paper is that he makes no mention of carbon at all. Judged by my results and by Mr. Bolton's results, it is simply an incidental phenomenon, but the total carbon is possibly an explanation of the thing that Mr. Gilderman is getting at on this chill. It is well known that the chill can be made to reach into the gray iron, and it can also be made of clear division. I haven't had much experience with chilled iron, but that is very noticeable in breaking car wheels. In the good car wheels the chill

always reaches in, and in the poor ones indicates a clear line. In his test bar he took care of his carbon, and the way the carbon is, as Mr. Bolton started out to say, twice carbon plus the silicon, is a factor in the governing strength, and he left out the greatest factor in it.

DR. MOLDENKE: When you have your iron melted, everything liquid, the temperatures the same, the method of pouring the metal the same, the sand the same, you ought theoretically to get the same result, but you don't. Therefore, have we got all the analysis? The oxides of iron, the hydrogen, there are a lot of things in that iron in very great quantities that we don't know about. If we had the complete analysis and had it under the very same conditions, the results should be the same. Some day we will know a little more about it. Mr. Gilderman has mentioned something about the line of the chill. When we have a highly oxidized material, high sulphur, high phosphorus, it seems as if the setting against the skin of the mold goes progressively inwards, direct; whereas, where you have a very pure metal, the setting goes off in lines, the crystals form inside these liquid spaces between the graphite, come out between them, so that it runs off into shades from the white to the gray. So that I think that has a great deal to do with the rate of cooling, depending upon the nature of the iron that you use.

B. D. FULLER: I had an experience which, while it has nothing to do with test bars, and therefore I don't know whether I should interject it here, still it was an enlightening experience in regard to that matter of the sharp line of demarcation. It was in endeavoring to make light resistance grids, introducing into them from 3 to 15 per cent nickel, a very low phosphorus and a high silicon. The object we wished to attain was that they give a much higher electrical resistance and give the casting what I would call a leaden quality; you could throw it around without breaking it. In endeavoring to get those castings at first we tried to make the mixture by heating the iron, melting the iron in the cupola, and melting our nickel separately, then mixing the two in the ladle. We tried and tried, but in every case, in trying to mix the thermo cast iron, the difference in the temperature, the difference in heating the metal from the cupola and then reducing it to the thermo was so great that the casting, when broken, showed the gray iron was always the core in the center and the nickel a sharp line right around the outside. You simply couldn't do it, and we lost the effect we were after. But take the same mixture melted in a crucible, all put in the crucible at the same time and brought up to the same heat in pouring, you could secure what you were after and you couldn't see any demarcation in the casting afterwards. I thought that was an interesting point, trying to mix iron to different temperatures, or metals. It doesn't have much bearing on this question of test bars.

D. J. KENNEDY: Mr. Gilderman mentions something about unreliable tensile tests of test bars. We noticed that where we worked, that one day the tensile test would be high, the next day it would be low, and we

finally found that when we took the test bar from the lower half of our transverse test—we would break the bar first with the transverse test—we found that our results agreed from day to day and showed that the same quality of iron was being made. Although the tensile test, I believe, is not a very good measure of the strength of the iron, we found we would get very good results from day to day.

DR. MOLDENKE: I would like to add to what our friend just said here about the tensile strength. It is a fact that you have to take the lower end of the bar if you want to get the correct result, but the tensile test is really unreliable in cast iron, on its own merits. I noticed that in a series of tests made for the Cast Iron Pipe Company, where with all their engineers, they mainly think in terms of tensile tests. That is because practically every metal, every alloy except cast iron, is homogenous, more or less, whereas cast iron is entirely different. So that we have to teach them that the transverse test is the nearest we can get to the idea. The upper part of those test bars would have a little more shrinkage than in the lower.

R. S. MCPHERRAN: As to the effect of minor amounts of materials present, I don't think we have ever gone into that sufficiently. In one of the papers this morning they referred to cast iron of the same analysis breaking diffierently. It is hard to know that it is the same analysis. I have been in the laboratory for 30 years, and I never saw two pieces of cast iron of the same analysis. We analyze cast iron for say 8 per cent of the material, and we simply guess the rest. We assume the other 92 per cent is all the same. I never saw a complete analysis of any sample of cast iron, but I ran across a day or so ago out of an old file a record of an analysis of iron and steel,[1] made in 1897, which determined the carbon and silicon content. The analysis given was: Carbon 2.257, silicon 3.265, phosphorus .459, sulphur .036, aluminum .028, chromium .027, vanadium .012, copper .009, nickel and cobalt .035, antimony .011, calcium .072, magnesium .100, titanium .025 and arsenic .015. Also, I should think, they might have found iridium and osmium and other metals more or less present if they had only gone after them. We simply assume in these comparative tests that all the other 92 per cent is alike. It is hard to explain why iron of the same analysis wouldn't have the same test, and the probability is that would show the same test if it was of the same analysis. Even this record here didn't in any way refer to any of the gaseous contents, which I think would affect our ideas very materially.

R. F. HARRINGTON: I would be interested in asking this gentleman who spoke about the testing of the lower end of the test bars as compared with the upper end, whether he noticed an appreciable difference in averages, finding that the lower end of the test bar, because of slightly different density, gave any higher tensile strength.

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[1] *Analysis Pig Iron.* Transactions British Iron and Steel Institute, 1897.

D. J. KENNEDY: Yes, we noticed quite a difference there. I haven't the figures with me, so I can't quote them, but for the matter of about a month we ran both ends of the test bar, and in every case of sound test bars the lower part of the bar ran higher than the upper part.

DR. MOLDENKE: I tried that same thing with the transverse test in this large series of tests that I spoke of, of cast iron pipe. We made quite a number of bars and broke them in half. Then we broke the other half. The lower half and the upper half were widely different. The upper half was always weaker than the lower half.

J. W. BOLTON: There is a factor there that perhaps is not considered. There is a difference between the upper and lower half of the test bar on account of the rate of cooling. This isn't so apparent in the smaller bar, inch and a quarter bar, but when you get into a bar, say 8 inches in diameter, it is very apparent, and taking bars poured at low temperatures you will find probably the same as with steel, that it indicates a difference in temperature. Of course, in the higher temperature bar you get a more uniform rate of cooling and don't have that trouble very much.

DR. MOLDENKE: I will add one more thing to this discussion, and that is this: Theoretically test bars should be absolutely the same from top to bottom, because you are putting in metal the same from top to bottom, but practically they are not.

R. F. HARRINGTON: This also is borne out in a practical way when, for example, a valve or piston packing is poured in a tube by the tensile screw method. This bears out Dr. Moldenke's point, that, although theoretically we should have the same metal from top to bottom, we have pressure which gives the greater density at the bottom and, consequently, higher tensile strength.

Characteristics That Chemical Analysis Fails to Disclose in Pig Irons and Castings

By W. E. Jominy, Ann Arbor, Michigan

There has been some disagreement among foundrymen as to whether or not cast irons of the same elemental chemical composition have the same or different characteristics when produced under varying blast furnace and cupola conditions. The controversy is particularly rife when the discussion of these variations leads to the subject of coke irons as compared to charcoal irons. It does not confine itself to these two types of irons. Many contend that different coke irons will have dissimilar characteristics even though the carbon, silicon, manganese, phosphorus, and sulphur contents may be the same.

The greatest differences of opinion, however, appear when coke and charcoal irons are considered. The considerable variations in the methods by which coke and charcoal irons are produced would certainly make the differences in characteristics much more pronounced between these two types of irons than would be expected between two different coke irons or two different charcoal irons of the same chemical composition.

Coke Furnace Conditions Different From Charcoal Furnace Conditions

It is customary to run coke furnaces with higher blast temperatures and pressures than are used with charcoal furnaces. The sulphur content in the coke requires a slag relatively higher in lime. The higher melting point of this limy slag makes it necessary to maintain a higher hearth temperature in the coke furnace than in the charcoal furnace. The latter can operate

with more acid and consequently more fluid slag because of the freedom of the charcoal from sulphur.

The coke furnaces, which produced the irons discussed in this paper, operated with an average blast temperature of 1300 degrees Fahr., and a blast pressure of 14 pounds per square inch; whereas, the charcoal furnace operated with an average blast temperature of 1050 degrees Fahr., and a pressure of 4½ pounds per square inch. The temperature of the iron coming from the charcoal furnace averaged about 300 degrees lower than similar iron from the coke furnaces.

There is considerable evidence of a practical nature which would tend to make one believe that there is a decided difference in the properties of the two irons. Many foundrymen have found that it is less difficult to obtain good castings when using pig iron from a charcoal blast furnace than when using pig iron from the usual coke furnace. There is need for more scientific verification of these practical observations.

Knowledge of Pig Iron Characteristics Limited

There are so many variables which enter into the making of good castings and poor castings that it has been difficult in the foundry to show conclusively the superiority of one iron over another. When trouble is experienced in making good castings it is very difficult to determine definitely whether the pig iron is the cause of this trouble or whether it is any one of the host of other variables which must be dealt with in the foundry. Our knowledge of the properties of pig iron is limited to interpretation of the chemical analysis, which as will be seen from the results of the researches herein reported, certainly offers little information concerning the strength and hardness of the iron. A considerable amount of written discussion has been published on the subject. The majority of this has been based on rather meager data.

J. E. Johnson, Jr.,[1] has probably written more to the point on this subject than any other investigator. He has reached some very definite conclusions with respect to the reasons why charcoal iron is superior to coke iron. He attributes the superiority to the

[1]American Institute for Mining Engineers, Vol. 50, p. 344 (1914).

presence of oxygen in the former. His conclusions, however, have only been supported by data from tests which he made on eight different pieces of iron.

The author has examined approximately one hundred samples of pig iron in the investigation recorded in this paper, which has been submitted to contribute sufficient reliable data to show that there are large differences in irons having the same chemical analysis and that these persist through the remelting. The results support most of Johnson's contentions regarding the superiority of charcoal irons. In addition, they show the variations of irons in strength, composition, and metallographic structure when produced in blast furnaces under known widely variant conditions.

No attempt was made to verify the relation of the oxygen content of the irons to their strengths as suggested by Johnson. Johnson used the Ledebur method for the determination of the oxygen and according to the findings of Cain and Pettijohn,[2] the Ledebur method for this determination is not strictly accurate. Since Johnson was dealing with such very small quantities of oxygen, a slight inaccuracy in the method might lead to errors of considerable magnitude. For this reason and the fact that no foundry laboratory is equipped to make these determinations, it has been endeavored to find some other characteristics or combination of characteristics by which the suitability of a pig iron can be determined.

How Samples Were Obtained

The samples of pig irons used in the tests were taken from time to time over a period of four months from five different blast furnaces. On many of the heats from which samples were taken, the writer noted the blast furnace conditions such as temperature and pressure of blast, and analysis of the slag run from the furnace just previous to the time of pouring. This was done in an effort to correlate the properties of the irons with some of these conditions at the blast furnace but no relation was discovered.

It was endeavored to have the irons poured under as nearly the same conditions as was possible. For this purpose, arbitra-

[2]Tech. paper 118, Bureau of Standards (1919).

tion test bar molds, made practically in accordance with the specifications of the American Society of Testing Materials, were used. They differed slightly in that the gate was made wider than that required in the specifications. This was done because it was desired to have sufficient material for remelting without having to use the test pieces proper. The pouring was accomplished by tapping off the iron as it flowed from the blast furnace into a ladle placed about 50 feet from the blast furnace and pouring from this ladle into the arbitration molds. The test bars thus produced were 1¼ inches in diameter by 15 inches long, and were shipped from the blast furnaces attached to the gates. There were two bars on each gate and hence of the same composition. The test bars were numbered as received in such a manner as to identify them with the heat numbers at the various furnaces from which they came. They are referred to in this report according to this number.

The only other variations from the specified procedure were that these test pieces were poured into undried molds at the coke furnaces. Dried molds were used at the charcoal furnace. Of necessity, the chemical compositions of the samples varied with different heats.

Tests Made

The test bars, as received, were broken from the gate and subjected to a transverse test. Tensile test specimens were then made from the lower half of each of the transverse specimens and the standard tensile test for cast iron was made on each.

Both Brinell and Rockwell hardness tests were made on the transverse specimens near the fracture. Many of the samples were likewise subjected to a metallographic examination at and near the fracture. An attempt was made to correlate the variations in physical properties with the chemical properties. It was impossible to observe any correlation whatever. Of course, the results of those test pieces which showed blow holes or slag or carbon inclusions in the fracture were discarded.

Some Interpretations of Data

The results of these observations on charcoal irons were put in Table 1 and those on the coke irons in Table 2. There are

data on 40 irons contained in these two tables. The results on the other samples were discarded either because of blow holes or slag or carbon inclusions in the fractures of the test pieces or because of a silicon content of less than 1.25 per cent. When less than this amount of silicon is present there is danger of a chilling effect, particularly when the irons are remelted.

The data were separated into the two tables and tabulated according to the silicon content for convenience of examination. All the data given for physical properties represent the average of two determinations for each iron. It will be noted that the average results for the charcoal irons are higher than those for the coke irons, even though there is no outstanding difference in the chemical compositions except perhaps the carbons and with these the difference is such as would normally be expected to favor the coke irons. The Brinell readings for the coke irons range from 121 to 159, whereas for the charcoal irons the limits were 134 and 171. The range of transverse strengths in pounds were for the coke irons, 1,700 to 2,900 and for the charcoal irons 2,100 to 3,050. The tensile tests showed results varying from 12,400 to 22,800 pounds per square inch for the coke irons and from 17,400 to 26,500 pounds per square inch for the charcoal irons. When it is remembered that the molds at the coke furnaces were of green sand and not dried, whereas, the molds at the charcoal furnace were dried, these results have added significance. It must be remembered that the iron from the coke furnaces was poured at a relatively higher temperature, about 300 degrees Fahr., in those observed by the author, than that from charcoal furnaces.

It is generally accepted that it is extremely difficult, if not impossible, to obtain satisfactory castings by pouring directly from the blast furnace into the molds. The results are in accord with this idea, only the averages being of any consequence.

How Iron Was Remelted

Therefore, in order to prepare the samples in a manner which would more satisfactorily permit of comparing results, the gates and unused portions of the samples were remelted in a Booth ladle type muffled arc furnace. The ladle was lined

Table 1

Properties of Charcoal Pig Irons

Iron No.	Si	Mn	S	P	C	Brinell	Rockwell B	Transverse strength pounds	Deflection inches	Tensile strength pounds per. sq. in.	Blast temperature	Blast pressure pounds	Slag SiO_2	Slag Al_2O_3
11	1.31	.54	.012	.136	4.22	159	78-88	2,750	.11	23,600	....	..	....	....
66	1.39	.48	.012	.149	4.17	152	72-78	2,350	.155	22,700	1,035	4	45.00	19.40
69	1.45	.50	.011	.138	4.18	149	68-74	2,300	.14	22,000	1,035	4	46.25	20.44
50	1.50	.41	.010	.136	4.05	151	69-79	2,500	.135	22,200	1,170	4	43.00	20.90
70	1.52	.58	.012	.147	4.14	156	73-82	graphite	...	22,000	1,045	4	45.25	18.80
61	1.53	.70	.011	.136	4.12	163	70-80	graphite	...	.....	....	..	44.00	20.69
58	1.62	.58	.010	.140	4.06	158	75-85	2,850	.15	.....	....	..	....	....
0	1.70	.62	.012	.136	4.21	151	75-80	2,650	.13	21,900	....	..	....	....
68	1.70	.58	.012	.162	4.13	156	63-74	2,650	.16	22,400	920	4	43.50	20.44
81	1.70	1.16	.015	.180	3.98	156	....	2,600	.13	22,000	1,120	4	46.00	18.81
49	1.78	.44	.008	.140	4.13	148	69-74	2,500	.16	22,200	....	5	38.50	21.32
80	1.82	1.48	.015	.188	4.15	152	....	2,700	.15	24,300	1,125	4	47.10	17.10
79	1.95	.54	.011	.14	4.05	156	....	3,050	.13	26,500	1,055	5	44.00	24.03
73	1.96	.42	.010	.166	4.24	149	65-75	2,500	.12	22,300	1,100	5	43.15	21.95
60	1.98	.70	.009	.133	4.19	156	63-74	2,700	.16	20,900	....	5	46.10	20.90
64	2.02	.70	.012	.137	4.17	153	72-78	2,600	.16	22,100	1,150	5	42.75	19.23
75	2.20	.49	.009	.166	4.04	171	72-78	2,500	.14	23,900	1,150	5	42.60	23.78
77	2.30	.49	.009	.130	4.23	149	....	2,700	.125	21,300	.980	4	38.50	25.18
78	2.40	.69	.010	.130	4.15	143	....	2,400	.13	22,200	1,020	5	46.75	21.74
48	2.63	.62	.006	.135	4.20	135	....	2,100	.125	17,400	1,220	5	44.50	19.02
72	2.68	.55	.008	.131	4.12	170	72-85	2,700	.105	24,300	1,070	5	44.10	19.44
74	2.69	.49	.009	.137	3.83	137	....	holes	...	21,400	1,120	5	46.10	22.68
47	2.72	.54	.008	.176	3.64	160	78-83	2,300	.105	22,400	....	5	45.50	18.29
76	3.02	.65	.009	.145	3.78	148	75-83	2,600	.13	25,600	1,083	5	40.60	23.87

Table 2

Properties of Coke Pig Irons

Iron No.	Si	Mn	S	P	C	Brinell	Rockwell B	Transverse strength pounds	Deflection inches	Tensile strength pounds per. sq. in.	Blast temperature	Blast pressure pounds	Slag SiO_2	Slag Al_2O_3
6	1.86	.91	.015	.133	4.04	143	70-76	2,900	.16	20,600	....	..	....	....
18	1.95	.94	.029	.520	3.85	159	81-86	2,500	.125	22,100	....	..	....	....
7	1.99	.77	.016	.133	4.06	143	71-77	2,900	.15	20,800	....	..	....	....
37	2.01	.81	.028	.163	4.20	131	....	2,400	.15	12,400	1,300	13	40.52	13.30
22	2.10	1.02	.04	.50	3.91	158	79-86	2,600	.125	21,200	....	..	....	....
36	2.13	.78	.026	.163	4.06	121	62-71	1,700	.115	15,000	1,275	12	40.52	13.30
19	2.17	.77	.033	.46	3.86	140	74-80	2,650	.16	18,600	....	..	....	....
38	2.43	.83	.023	.504	3.50	143	....	1,950	.10	14,800	1,300	13	38.70	14.68
23	2.46	1.08	.026	.464	3.64	154	78-85	2,450	.115	22,800	....	..	....	....
21	2.60	1.06	.024	.52	3.74	153	76-82	2,650	.15	20,200	....	..	....	....
4	2.67	.74	.027	.135	4.29	131	66-74	2,250	.12	17,200	....	..	....	....
3	3.08	.95	.020	.19	3.82	131	63-69	2,300	.13	16,500	1,300	15	....	....
20	3.17	1.07	.024	.480	3.81	143	78-83	2,350	.12	20,300	....	..	....	....
5	3.20	.89	.026	.273	4.14	130	60-78	Holes	...	Holes	....	..	....	....
1	3.33	.93	.023	.45	3.51	131	66-72	2,200	.12	17,500	1,300	15	....	....
2	3.63	.93	.023	.45	3.55	142	70-80	2,200	.115	19,000	1,300	15	....	....

All of these pig irons were cast into green sand. The molds for these bars were not dried in accordance with the A. S. T. M. specifications.

with a mixture of ganister and Thermolith cement. The pig iron samples were cut up, placed in this ladle, covered with charcoal and heated to the required temperature for pouring. It was endeavored to keep this temperature approximately 2,600 degrees Fahr. In general, with the furnace hot, from 30 to 40 minutes were required to bring the charge up to the required temperature. The temperature of the iron in the ladle was noted by means of an optical pyrometer. As soon as a satisfactory temperature was obtained, the ladle was removed from the furnace and the iron poured into an arbitration mold made strictly in accordance with the specification of the American Society for Testing Materials. Usually about one-half minute was required for the pouring of the iron, and on no occasion did more than a minute elapse between the time of taking the temperature reading and the pouring of the iron.

This furnace made possible a fairly accurate control of the pouring temperature. That the melting conditions were very satisfactory can be seen from Table 5 by noting the small variations in chemical compositions between remelts. Likewise, it was possible to clean the ladle after each heating, and thus eliminate the possibility of contamination of succeeding samples. Considerable care was taken to see that this contamination did not occur.

The same procedure was followed for testing the samples thus obtained as was used in the case of the original samples received from the blast furnaces. The samples obtained by remelting were stamped with the same reference number and a prefix X to show that they were remelts.

Data Obtained on Remelting

The results of the remelts of the samples recorded in Tables 1 and 2 are recorded in Tables 3 and 4. Because of mishaps and lack of sufficient time, only thirty-two of the forty irons shown in the former two tables are included in the latter two. The remelted irons are tabulated in the order of their silicon content. This order is not exactly the same because the silicon losses on remelting varied. The variations are not great, however, averaging only .05 per cent loss of silicon and .02 per

Table 3

Physical Properties of Remelted Charcoal Irons

Iron No.	Si	Mn	S	P	C	Brinell	Transverse pounds	Deflection inches	Tensile strength pounds per square inch
X11	1.27	.53	.012	.136	4.11	167	3,200	.15	28,850
X66	1.34	.43	.012	.149	4.08	159	2,750	.165	24,800
X69	1.41	.54	.011	.138	4.09	163	2,850	.16	25,200
X70	1.48	.61	.012	.147	3.97	158	2,800	.145	25,400
X49	1.65	.44	.008	.140	3.90	175	3,050	.12	29,200
X50	1.52	.41	.01	.136	3.99	179	3,300	.17	28,500
X0	1.70	.62	.012	.136	3.96	163	3,000	.155	25,850
X68	1.81	.56	.012	.162	4.07	159	3,150	.205	24,800
X73	1.82	.43	.010	.166	4.05	159	2,700	.14	25,900
X60	1.90	.70	.009	.133	3.90	195	3,700	.19	29,800
X64	1.91	.61	.013	.137	4.04	179	3,450	.13	29,900
X79	2.04	.54	.011	.140	4.00	170	3,350	.13	27,400
X75	2.15	.48	.009	.166	3.86	170	3,200	.13	30,400
X74	2.47	.49	.009	.137	3.79	167	3,500	.16	27,000
X72	2.57	.53	.008	.131	3.81	161	3,150	.15	28,500
X47	2.64	.54	.008	.176	3.60	159	2,500	.13	21,200
X76	2.84	.62	.009	.145	3.78	167	3,650	.135	31,500
AVERAGES						167	3,135	.152	27,247

Table 4

Physical Properties of Remelted Coke Irons

Iron No.	Si	Mn	S	P	C	Brinell	Transverse pounds	Deflection inches	Tensile strength pounds per square inch
X6	1.70	.91	.015	.133	3.91	151	2,750	.15	23,500
X37	1.99	.78	.033	.176	3.83	152	2,450	.17	21,600
X7	2.06	.74	.016	.133	3.89	163	2,900	.14	25,600
X18	2.09	.95	.029	.520	3.74	165	2,850	.15	22,600
X22	2.09	.99	.04	.50	3.73	163	2,600	.12	21,000
X36	2.10	.71	.026	.163	3.72	147	2,650	.155	17,100
X4	2.11	.74	.027	.135	3.85	151	2,300	.13	21,600
X19	2.21	.74	.033	.46	3.62	154	2,600	.15	19,000
X38	2.42	.80	.023	.504	3.51	161	2,550	.12	22,400
X23	2.44	.97	.026	.464	3.64	166	2,600	.15	21,000
X3	2.88	.95	.020	.19	3.56	149	2,700	.105	21,500
X20	3.25	1.03	.024	.48	3.44	156	2,500	.15	20,600
X5	3.27	.82	.026	.273	3.47	116	2,300	.10	18,200
X1	3.31	.89	.023	.45	3.32	140	2,030	.10	19,100
X2	3.67	.93	.024	.458	3.33	129	2,200	.10	18,200
AVERAGES						150	2,533	.132	20,806

cent loss of manganese in the remelting. Only a few values for phosphorus and sulphur were determined and as these checked within the limits of chemical error with those for the original samples, it was deemed unnecessary to make further analyses for these elements. It is evident from the chemical analysis that the melting conditions were slightly oxidizing.

Differences in Strength Greater on Remelting

From the data recorded in these tables, it will be seen that the differences in strength are even greater between the char-

Table 5

Effect of Remelting on Properties of Pig Irons

Iron No.	Si	Mn	S	P	C	Brinell	Transverse pounds	Deflection inches	Kind of Iron
60	1.98	.70	.009	.133	4.19	156	2,700	.16	
X60	1.90	.70	....	....	3.90	195	3,700	.19	Charcoal
XX60	1.83	.67	....	....	3.79	170	3,500	.18	
64	2.02	.70	.012	.137	4.17	153	2,600	.16	
X64	1.91	.61	.013	.136	4.04	179	3,450	.13	Charcoal
XX64	1.87	.57	.015	.139	3.96	167	3,300	.13	
37	2.01	.81	.028	.163	4.20	131	2,400	.15	
X37	1.99	.78	.033	.176	3.83	152	2,450	.17	Coke
XX37	2.03	.71	.038	.173	3.80	131	2,300	.115	
18	1.95	.94	.029	.520	3.85	159	2,500	.125	
X18	2.09	.95	....	....	3.74	165	2,850	.15	Coke
XX18	2.06	.95	....	....	3.74	170	2,800	.12	
75	2.20	.49	.009	.166	4.04	171	2,500	.14	
X75	2.15	.48	....	....	3.86	170	3,200	.13	Charcoal
XX75	2.11	.45	....	....	3.82	153	3,000	.12	
74	2.69	.49	.009	.137	3.83	137	Holes	...	
X74	2.47	.49	....	....	3.79	167	3,500	.16	Charcoal
XX74	....	...	....	....	3.67	166	3,550	.13	
47	2.72	.54	.008	.176	3.64	160	2,300	.105	
X47	2.64	...	....	....	3.60	159	2,500	.13	Charcoal
XX47	2.56	.48	....	....	3.53	149	2,800	.135	
76	3.02	.65	.009	.145	3.78	158	2,600	.13	
X76	2.84	...	.009	.139	3.78	163	3,650	.135	Charcoal
XX76	2.86	.65	.009	.131	3.72	170	4,000	.135	
2	3.63	...	.023	.45	3.55	127	2,200	.12	
X2	3.67	.93	.024	.458	3.33	128	2,200	.10	Coke
XX2	3.70	...	.028	.463	3.20	116	2,100	.125	

coal and coke irons than was the case before the remelting. A comparison of the tables will show that coke irons did not increase materially in strength on remelting. In general, the charcoal irons showed a decided increase in physical properties on remelting. This is probably due to the less favorable pouring conditions of the original samples already mentioned.

The Brinell readings on the coke irons given in Table 4 range from 116 to 166, while those for charcoal irons given in Table 3 range from 158 to 195. A comparison of tensile strengths for the two shows that the coke irons range from 17,100 to 25,600 pounds, while the charcoal samples range between 21,200 and 31,500 pounds per square inch. The average tensile strength for coke iron, 20,866 pounds per square inch, is below the lowest value found for charcoal iron, and the average

tensile strength for charcoal iron, 27,322 pounds per square inch, is above the highest value for coke iron. This same relation is evident for the transverse strengths. The coke irons vary between 2,030 and 2,900 with an average of 2,532 pounds; whereas, the charcoal samples give minimum and maximum values respectively of 2,500 and 3,700, with an average value of 3,188 pounds.

Fig. 1 showing the transverse strengths and Fig. 2 giving the tensile strengths, will perhaps present the picture more forcibly than it may be obtained from a comparison of the tabulated data. The data is plotted on silicon content as the abscissa.

These figures which represent the averages of many tests prove that there is good agreement between the strengths of the irons and the methods used to produce them. There can be little doubt that the coke irons tend to be weaker than the charcoal irons. Furthermore, the difference appears to be a chemical one because it persists through the remelting of the iron. Examination of Table 5 shows this difference to persist through a second remelt and removes any question of its effect.

Silicon Effect Does Not Show Well Defined Relationship

Strangely enough there is no well defined relation existing between the silicon content of the irons and their physical properties or between any of the commonly determined chemical elements and these physical properties. It must be borne in mind, however, that the effect of the silicon is minimized by the use of dried molds and the 1¼ inch section.

These statements do not mean that the physical properties would not be influenced by the addition of material quantities of these elements. They merely mean that within the limits in which the elements are present in the irons listed, they do not appear to account for the marked variations in properties which are noted.

Second Remelt Made

In order to show that the results obtained on the first remelt were peculiar to the iron, rather than the melting conditions,

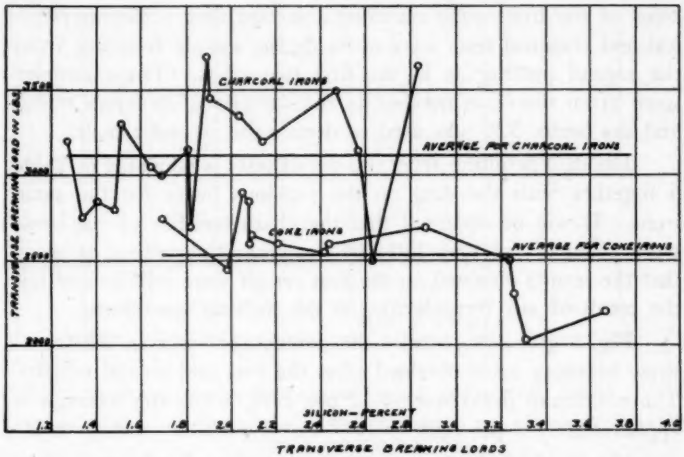

CHARCOAL IRONS
AVERAGE FOR CHARCOAL IRONS
COKE IRONS
AVERAGE FOR COKE IRONS
TRANSVERSE BREAKING LOAD IN LBS.
SILICON—PERCENT
1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0
TRANSVERSE BREAKING LOADS

FIG. 1—CHART SHOWING COMPARISON OF TRANSVERSE STRENGTHS OF CHARCOAL IRONS AND COKE IRONS

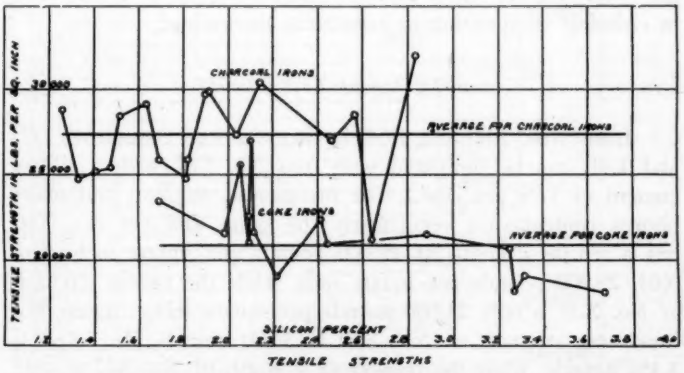

CHARCOAL IRONS
AVERAGE FOR CHARCOAL IRONS
COKE IRONS
AVERAGE FOR COKE IRONS
TENSILE STRENGTH IN LBS. PER SQ. INCH
30,000
20,000
SILICON PERCENT
1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0
TENSILE STRENGTHS

FIG. 2—CHART SHOWING COMPARISON OF TENSILE STRENGTHS OF CHARCOAL IRONS AND COKE IRONS

some of the irons were remelted a second time. Similar physical and chemical tests were made on the sample resulting from the second melting as in the first two cases. These samples were given the same number as the samples of previous melts, and the prefix XX was used to denote the second remelt.

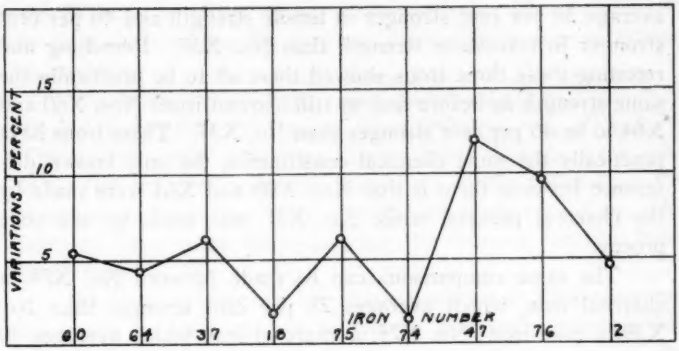
The data resulting from this set of tests is tabulated in Table 5 together with the data on the previous heats for the same irons. It will be observed that the characteristics of the irons were changed but very little by the second remelting, proving that the results obtained on the first remelt were reliable and not the result of any irregularities in the melting conditions.

Fig. 3 gives graphically the percentage error in the transverse breaking loads obtained after the first and second remelts. The maximum difference is 12 per cent, while the average is approximately 5 per cent.

Fig. 4 gives the comparative strengths of coke and charcoal irons of practically the same chemical composition. It is practically impossible to get different samples from the furnaces and remelt them to give exactly the same metalloid content. It is believed that the irons compared are near enough alike in this respect to show conclusively that there is a decided difference in the characteristics which cannot be accounted for by a difference in chemical composition as commonly determined.

Comparison of Test Results

Irons Nos. X60 and X64, having a silicon content of 1.90 and 1.91, can be compared with iron No. X37 with a silicon content of 1.99 per cent. The manganese, sulphur, and phosphorus contents are very nearly the same, and yet No. X60 has a tensile strength of 29,800 pounds per square inch; No. X64, 29,900 pounds per square inch, while the tensile strength of No. X37 is only 21,600 pounds per square inch. Again, the transverse strength of No. X60 is 3,700 pounds; No. X64 is 3,450 pounds, while the transverse strength of No. X37 is only 2,450 pounds. Remelting and retesting these three irons gives a transverse strength for No. XX60 of 3,500 pounds; No. XX64 of 3,300 pounds, and No. XX37, 2,300 pounds. The two irons, Nos. X60 and X64, having about the same strength,



VARIATIONS IN BREAKING LOADS WITH REMELTING

FIG. 3—CHART SHOWING PER CENT VARIATION OF BREAKING LOADS OF IRONS ON REMELTING

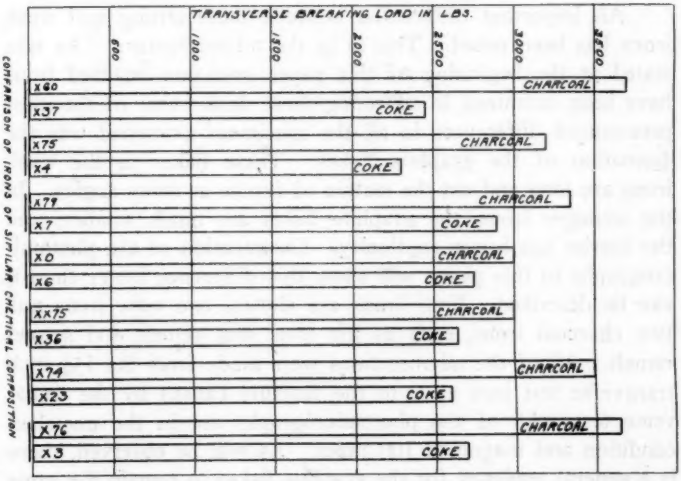


FIG. 4—COMPARISON OF IRONS OF SIMILAR CHEMICAL COMPOSITION

average 38 per cent stronger in tensile strength and 46 per cent stronger in transverse strength than No. X37. Remelting and retesting these three irons showed them all to be practically the same strength as before and so still showed irons Nos. X60 and X64 to be 46 per cent stronger than No. X37. These irons have practically the same chemical constituents, the only known difference between them is that Nos. X60 and X64 were made by the charcoal process, while No. X37 was made by the coke process.

The same comparisons can be made between No. X74, a charcoal iron, which averages 28 per cent stronger than No. X38, a coke iron; No. X75, a charcoal iron which averages 40 per cent stronger than No. X4, a coke iron; and between No. X76, which averages 41 per cent stronger than No. X3, a coke iron. The outstanding difference which corresponds to difference in strength between these irons is the process of manufacture.

Microstructure Shows Differences in Graphite Formation

An important differential between these strong and weak irons has been noted. This is in the microstructure. As was stated at the beginning of this paper over one hundred irons have been examined in collecting these data. One of the most pronounced differences in all the specimens examined was the formation of the graphite flakes. These flakes in the weak irons are long and cut the matrix of ferrite at many angles. In the stronger irons, the graphite flakes are much smaller, and the ferrite has better continuity. Examination of the photomicrographs in this paper will show this difference better than it can be described. Four irons are shown, two coke irons and two charcoal irons, each as pig iron, first remelt and second remelt. All of the microsections were made from the 1¼ inch transverse test bars close to the fracture caused by the transverse test. All of the photomicrographs are in the unetched condition and magnified 100 times. As will be observed, there is a general tendency for the graphite flakes to remain the same through the remeltings, although in both charcoal irons the graphite flakes seem to be refined in the first remelt. It may be that the poor casting condition as previously described caused

the flakes to be rather coarse in the pig iron. There appears to be little tendency for the graphite in the coke iron to be refined in remelting.

The writer does not claim that all coke irons look like Nos. 37 and 2, nor that all charcoal irons look like Nos. 60 and 76. The stronger coke irons have smaller flakes than the weak coke irons and the weak charcoal irons have larger flakes than the strong ones. However, there is a distinct tendency for the coke irons to have large flakes and for the charcoal irons to have small flakes.

While this difference in microstructure has been observed, no reason for its cause can be given. It is logical enough that the strength of the metal should vary with the size of the graphite flakes but what causes the variation of the graphite flakes? The author hopes that further work may be done on this problem and that some relation will be found between blast furnace conditions and the production of high grade iron, so that the variation in characteristics of pig irons of the same chemical analysis may be controlled, and poor pig irons eliminated.

FIG. 5—No. 60 UNETCHED X100. CHARCOAL PIG IRON; SILICON, 1.98 PER CENT; TRANSVERSE STRENGTH, 2,700 POUNDS

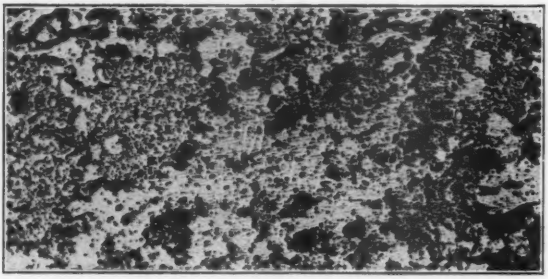


FIG. 6—No. X60. UNETCHED X100. REMELTED CHARCOAL IRON; SILICON, 1.90 PER CENT; TRANSVERSE STRENGTH, 3,700 POUNDS

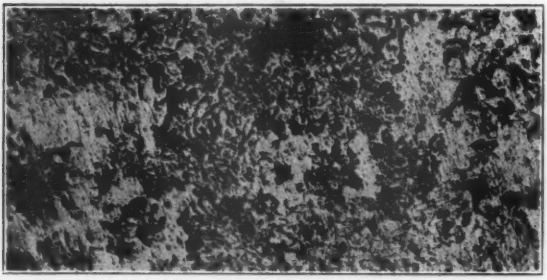


FIG. 7—No. XX60 UNETCHED X100. SECOND REMELT CHARCOAL IRON; SILICON, 1.83 PER CENT; TRANSVERSE STRENGTH, 3,500 POUNDS

FIG. 8—No. 37 UNETCHED X100, COKE PIG IRON; SILICON, 2.01 PER CENT TRANSVERSE STRENGTH 2,400 POUNDS

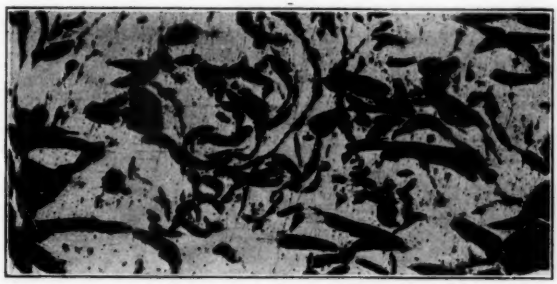


FIG. 9—No. X37 UNETCHED X100. REMELTED COKE IRON; SILICON, 1.99 PER CENT; TRANSVERSE STRENGTH, 2,450 POUNDS

FIG. 10—No. XX37 UNETCHED X100. SECOND REMELT COKE IRON; SILICON, 2.03 PER CENT; TRANSVERSE STRENGTH, 2,300 POUNDS

FIG. 11—No. 76 UNETCHED X100. CHARCOAL PIG IRON; SILICON, 3.02 PER CENT; TRANSVERSE STRENGTH, 3,650 POUNDS

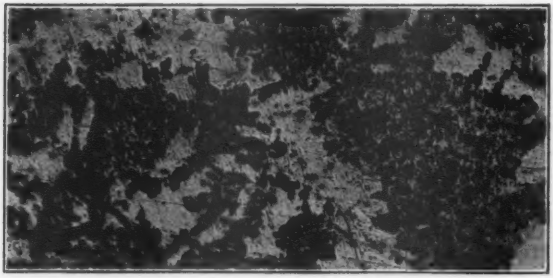


FIG. 12—No. X76 UNETCHED X100, REMELTED CHARCOAL IRON; SILICON, 2.84 PER CENT; TRANSVERSE STRENGTH, 3,650 POUNDS

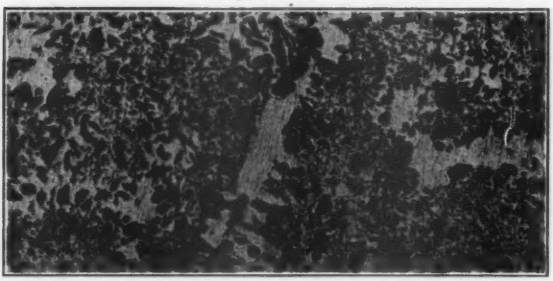


FIG. 13—No. XX76 UNETCHED X100. SECOND REMELT CHARCOAL IRON; SILICON 2.86 PER CENT; TRANSVERSE STRENGTH, 4,000 POUNDS

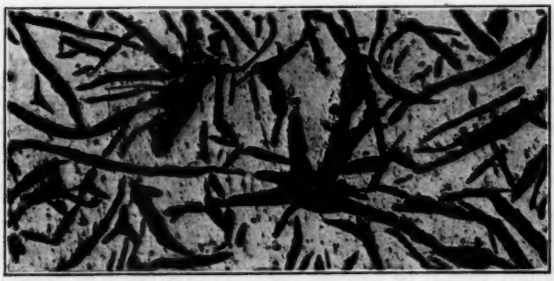


FIG. 14—No. 2 UNETCHED X100. COKE PIG IRON; SILICON, 3.63 PER CENT; TRANSVERSE STRENGTH, 2,200 POUNDS

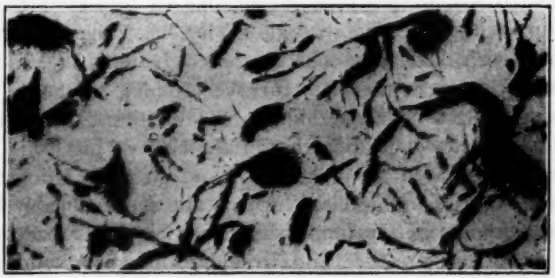


FIG. 15—No. X2 UNETCHED X100. REMELTED COKE IRON; SILICON, 3.67 PER CENT; TRANSVERSE STRENGTH, 2,200 POUNDS

FIG. 16—No. XX2 UNETCHED X100. SECOND REMELT COKE IRON; SILICON, 3.70 PER CENT; TRANSVERSE STRENGTH, 2,100 POUNDS

Discussion — Characteristics That Chemical Analyses Fail to Disclose in Pig Iron and Castings

By E. J. Lowry, Chicago.

The paper written by W. E. Jominy, undoubtedly carries data which should be of considerable importance to every foundryman who is interested in the consistent production of high grade castings. I cannot help but quote Dr. Moldenke in bearing out this thought:

"All of us, having seen the passing of cold-blast charcoal iron, and witnessing the struggle of hot-blast charcoal iron to continue, wish that many coke irons were better made, and look for improvement in the blast furnace product, so that rational remelting practice will give higher grade castings. It is becoming more and more apparent that in any class of pig irons, those which have enjoyed an undisturbed and effective reducing action by the gases of the blast furnace are unquestionably better for the purposes of the foundryman than pig irons made under high production pressure and irregular operation conditions."

It is true that coke furnaces produce irons under different conditions than charcoal furnaces. By reference to Table 1 the conditions shown by the average structures of the furnaces used becomes apparent.

Table No. 1

	The Coke Furnace	*The Charcoal Furnace*
Height	89 feet	60 feet
Bosh Diameter	23 feet	11 feet
Hearth Diameter	20 feet 11 inches	6 feet
Stock Line	10 feet	5 feet
Bosh Angle	89 degrees	86 degrees
Blast temperature	1000°–1400°F.	800° –1200°F.
Blast pressure	12 – 20 pounds per sq. in.	3½– 6 Pounds per sq. in.
Size charge	13000 –25000 pounds	1200 –1800 pounds
Amount of Limestone	3000 – 5000 pounds	40 – 60 pounds.
Daily production	300 – 650 tons	40 – 120 tons.

In considering the quality of pig iron, one should reflect upon all the factors entering into its production. Unquestionably,

the kind of fuel used in a furnace has its relative bearing upon the quality of the iron produced. This is possibly due to the length of the flame produced in the furnace with its consequent effect upon hearth temperatures and the point of formation of the "metallic sponge." Disregarding the factor of fuel, the next in importance is the temperature of the blast entering the furnace. This becomes the governor of the amount of fuel used. The lower the blast, the more the fuel. The amount of fuel used determines, to an extent, the production of a furnace; the more the fuel, the smaller the production. What then, is the result? The time given for reduction in the furnace is lengthened and the ore becomes well "cooked" with a resulting high carbon excellent iron. This, then, is an important question in the production of high quality iron, whether it be of charcoal or coke origin.

The next question of importance is the type of slag of the two operations. The coke furnace runs a "limey" slag, while the charcoal furnace is siliceous. There is a great difference in the product made under these two distinct conditions. The answer lays in the "inherent" zone, but it is comparable to basic and acid steels where the latter reigns in superiority.

When one considers the production of coke furnaces, of the dimensions shown in Table 1, it is found that they vary between 350 and 650 tons per day, while the charcoal furnaces shown produce between 45 and 75 tons per day. If the melting capacities of coke furnaces were in true proportion to their ability to properly smelt ores for comparisons with charcoal irons, their tonnages would drop, from those stated above, to from 200 to 350 tons per day. These figures rather prove that the coke furnaces daily overproduce to the sacrifice of charcoal iron quality. Hence, the other difference in these two type irons is the variation in the time the ores are held in their respective furnaces for proper reduction.

From the foregoing it becomes obvious that the factors entering into the smelting of ores in these two processes are widely divergent. The question of good iron revolves around the type of the burden, or raw materials, entering the furnace and the time given this ferrous material for proper reduction. The

coke furnace is operated upon a production basis with an attempt to obtain quantity, whereas the charcoal furnace obtains quality at the cost of quantity.

It must be said that there are several kinds of charcoal irons produced. The character of these irons may be judged solely by the furnace practice. Like the coke furnace, the charcoal iron furnace has had its practice changed depending upon the ideas of the owner and producer. It is essential that in the production of good charcoal iron the blast temperature be kept low and the amount of fuel relatively high. This gives a high carbon, well-smelted iron. In other words, even in charcoal irons where the temperature of the blast is high and the amount of fuel low, the ore is not given the opportunity to be well "cooked," with a consequent effect up on the pig iron.

Mr. Jominy states that many foundrymen have found it less difficult to produce good castings with charcoal iron. There is no reason to doubt this statement when one considers the variation which is found in a car of pig iron. If we go back to the furnace, we find that a charcoal iron furnace tapping approximately 15 tons will have at least five different grades in each cast, providing the furnace is properly operated. These casts will vary from a No. 3 Low to a No. 5 High, or from a Scotch A to a No. 1 High and so on. It is exceedingly difficult to get uniformity throughout the cast from any furnace. The charcoal iron furnaces, realizing the necessity for careful grading, analyze each ton of iron cast and also grade the "pigs" by fracture.

In contradiction to this, the coke iron furnace will make its tap of at least 100 tons and with a furnace cast analysis take it for granted that the iron is uniform throughout. As a result of this, cars of coke iron have been known to vary 60 points in silicon in the pigs which were analyzed. There are many instances where coke irons will run normally uniform, but the chances are that there will be some variation. Then, why isn't it reasonable that foundrymen should find that charcoal iron will produce more consistent good castings than the average carload of coke irons? (1) Ease of manipulation in the raw materials entering a cupola, (2) uniform analyses in these raw materials,

and (3) good melting practice aid in the consistent production of gray iron castings. Charcoal iron will give the first two requisites, while the last must come as a reward to the effort of the foundryman.

Regarding the research of J. E. Johnson, Jr., and his belief that oxygen proved the important factor of charcoal iron: It is believed that Mr. Johnson's contentions were based upon too few tests to be taken as conclusive, and that the method used in the determination of oxygen by Mr. Johnson was not of a strictly accurate nature. Therefore, the fact that oxygen leads to the strengthening qualities of charcoal iron, must be questioned. In fact, it is now acknowledged that oxygen often times proves a weakener of cast iron due to its creating chill and sluggish qualities in the iron. In the same light of Mr. Johnson's conclusions, it might be taken for granted that the attributed qualities of Swedish charcoal iron is due to the fixed nitrogen in the iron and to the presence of vanadium. But, such an assumption would be no more than a guess. It is felt that the quality of iron is more directly related to the type of raw materials entering the burden and to the proper metallurgical reactions taking place within the furnace, rather than attributed to some other rarer element.

It is believed that a contention will be made that coke irons with steel added in a mixture will give stronger results than those shown in Tables 3, 4 and 5 of Mr. Jominy's paper. It has been found that such is the case. But further, when charcoal irons and steel are mixed, a greater strength is found by this steel mixture than from the coke iron mixture. Some results of such mixtures are published in the Purchasing Agent's magazine of September 10, 1924. Due to the short space allowed for discussion, a reference is made to this article, rather than quoting it.

The tests taken by Mr. Jominy bear out the contentions of many melters. They clearly show that charcoal iron has some characteristic by which it is able to give increased strength with increased deflections over coke irons of a nearly similar analysis.

The statement: "Furthermore, the difference appears to be a chemical one, because it persists through the remelting of the

iron" seems to need some qualification. Refefring to the photomicrographs on pages 492 and 493, of Mr. Jominy's paper, a difference exists in the structure of carbons which results from the remelting of charcoal iron and coke iron. It can only be taken for granted that the specimens from which these structures were taken were cut from likely points on the test bars. If such were the case, there is a distinct difference which leads to the strong results obtained in the charcoal iron. The charcoal iron, as has often been shown, has carbon flakes considerably smaller than those produced in coke irons. This factor is perhaps the major one in giving the increased strength and it is not purely a chemical relation. Rather, it is a physical condition which enters into the strengthening of charcoal irons. This action of smaller carbon flakes may be the result of a physico-chemical relation set by the smelting operation.

It is not contended that charcoal iron is essential in the production of all grades of castings. Experience of foundrymen has shown that in some cases its use is not necessary. It has been found that by careful manipulation and less scrap in the cupola, a coke iron is used successfully. This fact is evident when the decreasing production of charcoal irons is observed. Therefore, both irons must have their specific uses and these are based more or less upon the castings which must be made. As an instance of this, chilled rolls may be made with coke irons of a malleable bessemer grade, but those rolls made from such mixtures are not of the same character as rolls which are made from charcoal iron mixtures.

The charcoal iron roll has a "fingery" chill, while the coke iron goes abruptly from the chill to the gray structures. The type of the dendrites are markedly different and superior in the charcoal iron when compared to the coke iron mixture. In the same vein it might be said that the character of chills produced from hot blast charcoal irons are different from those made from semi-warm and cold irons. The same holds true for other types of castings made with varying grades of pig iron. Therefore, the grade of iron to be used should be governed by the quality of the casting required.

In conclusion, the merit of charcoal iron lays in the process

by which it is manufactured and due to the long time of the ores in the furnace, they become thoroughly reduced to end where quality pig iron results.

Discussion—Characteristics That Chemical Analysis Fails to Disclose in Pig Irons and Castings

By H. A. SCHWARTZ, Cleveland, O.

Mr. Jominy has clearly shown that gray iron made from certain charcoal irons is, on the average, stronger than certain other gray irons made from coke pig iron. The present writer holds no brief either for or against the use of one or the other of these varieties if pig iron in the manufacture of gray iron castings. Neither is he especially conversant as an expert with the metallurgy of that product. He ventures, however, to make certain suggestions on the basis of general metallurgy rather than on the basis of any specialized knowledge which may, perhaps at least to some extent, clear up matters frequently overlooked by those discussing the properties of gray cast irons in terms of chemical composition.

Mr. Jominy has clearly shown on the basis of microscopic evidence, that the properties of his test specimens are, in large measure, accompanied by corresponding changes of microstructure. He has shown further, that these changes of microstructure deal with the interruption of the metal by graphite flakes. Unfortunately, however, in his tabular presentation of data, there is no information regarding the relative amounts of graphite and combined carbon, but only a statement of total carbon for each of the metals investigated. If investigators publishing the results of tests of gray iron would form the habit of invariably recording separately, graphitic and combined carbon in their particular specimens at, or very near the point of failure, there would be a better opportunity to determine whether or not

the observed physical properties could be correlated with chemical characteristics.

It should be observed in this connection, that the preparation of a suitable sample for determining correctly the relative amounts of free carbon and graphite is not easy, and involves very special precautions which, if not observed, may make such results quite meaningless. The present writer's preference is the collection of the dust removed when cutting through the material with a hack saw, a sufficient saw cut being made so that the entire amount of material so removed can be burned in a single determination, thus avoiding the possibility of a separation of fine graphite from coarse iron particles when a larger sample is prepared from which the analytical sample is to be later removed.

As has been stated by Mr. Jominy, the physical properties of a gray cast iron are largely an expression of the quantity and distribution of its graphite content. To this might be added that the combined carbon content is probably the determining factor with respect to the physical properties of the metallic matrix. The determination of the usual five elements is, therefore, of application only in so far as such an analysis can be translated over by the reader into a conception of a free and combined carbon content of the alloy as a whole. Such a translation is of necessity extremely difficult, since it involves consideration as to cooling rates, etc., which are not at hand in interpreting the results.

If this brief discussion will influence future experimenters to give data with respect to free and combined carbon, the present writer's end in submitting this discussion will have been achieved.

Discussion—Characteristics That Chemical Analysis Fails to Disclose in Pig Irons and Castings

By H. J. Young, Wallsend-on-Tyne, England

This paper is remarkable in that, to an even greater extent than previous papers on this subject, it ignores those results which are unfavorable to its dogmatic title. Moreover, it camouflages itself by means of a large number of figures having no bearing whatsover upon the point. For instance, only 13 irons in Table 1 are comparable with only 16 irons in Table 2, but those tables contain 24 and 20 irons respectively. The first two charcoal irons in Table 1 have a silicon content unlike any irons in Table 2; and the last four in Table 2 have a silicon content unlike any irons in Table 1. Therefore, of a total of 44 irons presented by the author, only 29 can be used legitimately for the subject under review.

The first two tables, when inspected, show that the irons of both kinds, namely charcoal and coke, give remarkable similar results:

Table 1 (Charcoal Irons)

Silicon	Transverse strength lb. per sq. in.
1.82	2,700
1.95	3,050
1.96	2,500
1.98	2,700
2.02	2,600
2.20	2,500
2.40	2,400
2.63	2,100
2.69	2,700
3.02	2,600
Average	2,585

Table 2 (Coke Irons)

Silicon	Transverse strength lb. per sq. in.
1.86	2,900
1.95	2,500
1.99	2,900
2.01	2,400
2.10	2,600
2.17	2,650
2.43	1,950
2.60	2,650
2.67	2,250
3.08	2,300
	2,510

Therefore, by comparing the only comparable irons in the author's lists one obtains figures showing the most remarkable similarity.

The author goes on to say: "That the melting conditions were very satisfactory can be seen from Table 5 by noting the small variations in chemical composition between remelts." Ex-

amination of Table 5 shows that charcoal iron No. 60 contained 4.19 per cent carbon and that it lost 0.40 per cent during two remelts; but charcoal iron No. 64, containing 4.17 per cent carbon lost only half that amount, namely, 0.21 per cent; and charcoal iron No. 76, containing 3.78 per cent, lost only one-seventh that amount, namely 0.06 per cent. Coke iron No. 18 contained 1.95 per cent silicon and during remelting gained 0.14 per cent; but charcoal iron No. 64, containing 2.02 per cent silicon, during remelting lost 0.11 per cent. If this is what the author calls "very satisfactory melting conditions" it is not remarkable that his conclusions are equally amazing.

In Fig. 4 the author gives a chart showing the superiority of charcoal irons over coke irons. He does not mention, however, that another chart could be made showing the superiority of some charcoal irons over other charcoal irons of no more dissimilar composition that the author allows in his chart. For instance, remelted charcoal iron 72x is similar to remelted charcoal iron 47x but there is no less than 1,000 pounds difference in the transverse test; and precisely the same remark and figure applies in the case of remelted charcoal iron 73x and compared with remelted charcoal iron 60x.

The whole of the results are prejudiced and do not prove even that which we know to be true, far less what the author wishes us to believe. As a matter of fact, the author, in his zeal, has thrown discretion to the winds to prove that which his results did not.

Some charcoal irons are superior, probably, to some coke irons for reasons which the author has not touched upon and not by possessing any mysterious property. This is true in spite of the fact that the author's figures suggest that there is little difference between them. He has been blind to certain facts which are very prominent in the compositions of the irons upon which he has worked; perhaps, if he will consider more deeply the case of basic steels as compared with acid steels he may, from that, find a reasonable course of study in the case of these irons. But he will need to compare those of similar composition only; there are very few, if any, in the paper under consideration.

Discussion—Characteristics That Chemical Analysis Fails to Disclose in Pig Iron and Castings

CHAIRMAN H. B. SWAN: I would like to point out that I believe this is a problem with which we are all more or less familiar from our own experiences. We all find a time when we can buy certain grades of pig iron from certain furnaces that give us good results, and certain characteristics, and we may buy a product of another furnace and find out that we run into certain difficulties, and yet your chemical analysis may be the same. You are at a loss to account for it. The thing rather dovetails with what has been brought out this morning in regard to the investigation of what is good pig iron, and also the fact that when we specify carbon, silicon, phosphorous and manganese, we don't tell the whole story. There are a good many who believe that there are other elements present that ought to be investigated, notably the gases, such as oxygen and nitrogen. So I think that while Mr. Jominy's paper only presents one phase of this question, it is very interesting and well worth your close attention.

I note that on the last page of Mr. Jominy's paper he says: "While this difference in microstructure has been observed, no reason for its cause can be given." Several years ago I did some work along the same lines as Mr. Jominy's paper. While he remelts his metal in an electric furnace, we remelted our metal in a cupola, and we still found that even blending the charcoal iron with the coke iron we could distinguish the peculiar graphite formation in the finished products which contained the charcoal iron. I think the gist of the paper is right there. Why do we find this difference?

W. E. JOMINY: I want to thank Mr. Lowry for his discussion and the bringing out of certain points. His point of physical conditions entering into the strength is correct as far as it goes. That is, he says that physical conditions enter into the strength of the iron. He says it is true that the strength of the iron is due to the physical condition of the graphite flakes. In that respect I think Mr. Lowry and I agree. But what is the cause of this particular physical condition? Why is it that when you remelt the iron the graphite flakes again precipitate to the same size as they were before? Is that not due to a chemical constituent which affects the size of the graphite flake?

In regard to the silicon content, I don't think you will find any very regular change on the part of either the charcoal or the coke iron. That might be partly explained by telling you the lining I used. It is given in the paper. It is a mixture of thermolith and ganister mixed in equal proportions and the iron was able to attack that cement in any case. In

one case it dissolved a little silicon and in the other case lost a little. Then again the gates were used in remelting the iron, and it is possible that there wasn't quite the same silicon content in the gate that there was further down in the tensile bar.

I might ask Mr. Lowry whether, in his opinion, or in his discussion of this paper, he has thought about the variations that are obtained in both irons, both the charcoal and the coke irons, from day, or from heat to heat, which apparently are not accounted for by the blast furnace conditions? The temperature of the blast is about the same, the pressure is about the same, the acid slag is about the same, and the charges, although not exactly the same, are not very different. It would, I think, help in the manufacture of good pig iron to know whether there are any particular set of conditions which will produce the highest grade of iron which we have here and eliminate those conditions which have produced the poorest grade of irons we have here, either considering the coke furnace irons together, or considering the charcoal iron furnaces and the charcoal iron we have produced.

E. J. Lowry: You have about as much control as you have over an unruly child. It is just by the grace of God that your iron comes out. That is about the only answer you can give to it. With a coke furnace operating upon a limey slag, the lime tends to stick to the lining of the furnace. When the lime sticks to the lining of the furnace you get what we call a "hanging furnace," or immediately after the hanging you get a "slipping furnace." Under such conditions the quality of your iron will vary. In order to counteract that action some furnace men do what they call "scour" their furnace. They put in materials which are highly oxidized, and which carry large amounts of silica. Those materials will affect the iron produced. I know of one firm which makes a weekly practice of scouring its furnace. It produces a more uniform grade of iron, but in that practice it doesn't produce an iron which perhaps is as good an iron as a furnace where you wouldn't have to scour it in order to make it run regularly. The speed of production is governed by the gases themselves, and there has no one yet been able to solve the matter of getting the proper balance in order to get perfect production.

J. T. MacKenzie: In talking over this question everybody seems to hand it to the gaseous content of these metals. Recently I had occasion to submit a very highly oxidized sample of cupola metal to Louis Jordan of the Bureau of Standards, who was working on that problem, and I also sent him one of our ordinary irons for comparison. He is using an induction furnace, keeping the metal at a very high temperature and drawing off the gases, the actual gas content which, of course, in the case of cast iron, would result from the reduction of the oxides in solution by the carbon present. On the oxidized cupola iron he reported an oxygen content of .018 per cent, and on the normal cast iron he gave me an oxygen content of .001. In other words, the iron that showed

the high shrinkage and all the evil effects that we commonly associate with oxygen, having 18 times the oxygen content of the normal iron. Now, you can't conceive of one iron having 18 times as much silicon as the other, or sulphur, or copper, or practically anything else. That is the most enormous difference between any two cast irons I think I ever saw.

D. J. KENNEDY: I think it is rather unfortunate that Mr. Jominy did not determine the combined carbon in his irons. We all know that combined carbon has quite a large strength, although one of the greatest effects is the condition of graphite. Referring to these photo-micrographs, those of coke irons are rather characteristic of irons low in carbon. Charcoal iron has a graphitic structure, usually very high in combined carbon, so that naturally it would be strong. I would not make any attempt to explain it, but I just want to call it to your attention.

W. E. JOMINY: In answer to the criticism of Mr. Kennedy and also Mr. Schwartz, I didn't see how the determination of combined carbon would account for the differences that we get between charcoal and coke irons. Supposing we were to get more combined carbon with the charcoal than we did with the coke irons, what causes it? However, I think, from the standpoint of general information, it would be well to include graphite. It was only because it was a long determination and hard to get at that it wasn't done. From the metallographic standpoint, however, I found that the combined carbon for iron No. X37, is 0.62. The combined carbon for the iron across the page is 0.59. The combined carbon for iron No. X18, which is given in Table 5, which is a coke iron, is 0.65. And I have a combined carbon for an iron which runs higher in silicon, iron No. X3 in Table H. That is 0.35. It seems to me that the effect of the graphite flake overshadows the effect of the combined carbon where you have different irons. If you were to use the same iron and add silicon to it, I think you would get a decided difference in the strength, due to the combined carbon, but when you have varying graphite flakes along with that the size of your graphite flakes may entirely overshadow the strengthening effect of the combined carbon. After all, isn't that what we get in malleable iron? You have there pure iron, no carbon at all, and it is stronger than gray iron; but the gray iron is weaker because of the form of the graphite flakes.

A MEMBER: Without attempting to make any comment upon the difference between the gas content of these irons in these photo-micrographs that are submitted, we have found it possible to produce the same conditions in structure and strength by variation of the cooling rate.

I would like to suggest that instead of looking entirely toward the question of gases in solution, we consider more carefully the influence of gases upon the cooling rate; also the possibilities of temperature of melting in the manufacture of the iron, and also in the process of remelting, upon the solubility of the graphite in the cast iron. Now, for example, if you take aluminum oxide; aluminum oxide, precipitated

gelatinously is very easily siphoned but produced at a very high temperature it is very difficult to siphon. And such a thing may account for these differences, without even considering the gas content.

DR. R. MOLDENKE: One word of caution. Whenever I see an analysis, "combined carbon," I feel like quoting Pontius Pilate, "What is truth?" What does combined carbon mean? If you take it from the skin it is one thing, if you take it from the inside it is a different thing. If you drill through the whole metal and get the average, what does that mean? It means nothing. Of course, it is important.

W. E. JOMINY: The coke irons were cast in an A. S. T. M. mold. The total carbon was obtained by taking three drillings across the piece on which we took the hardness test. Then in order to get our combined carbon we drilled in the same three holes, taking a composite sample, that is to say, taking a sample of the entire sample. We took the total carbon in the same way, taking a composite sample.

J. W. BOLTON: We made some carbon determinations which caused us to change our ideas. The nitric acid method is most generally recommended, and to test that out we annealed an iron completely to get all the carbon in the form of graphite. Therefore our graphite determination should show the same carbon as our total carbon. We got 3.38 total carbon on the average straight carbon; nitric acid, 3.28; hydrochloric acid, 3.35. That's a small difference between hydrochloric, .03 of 1 per cent, but a considerable difference between the nitric. Before we talk too much about the combined carbon, I think we had better consider more carefully our analytic methods.

CHAIRMAN H. B. SWAN: I am sure this discussion is very helpful, in view of the work that the committee on gray iron hopes to undertake. Just one thought occurs to me in the various points that have been brought out about oxidation, as to whether or not oxygen is present. I believe yesterday morning, in the electric furnace session, the point was brought up that, according to the researches of two Japanese, oxygen is absolutely essential to the graphitization of pig iron and cast iron.

H. F. STALEY: In regard to the effect of rare elements on known elements in the crystallization of the graphite—when they say that in other branches of industry, for instance in geology, it is found that very small amounts of certain elements have a very decided effect on the type and size of the crystallization of those elements. For instance, in the crystallization of granite, the presence of a very small amount of a certain element, an amount almost impossible to detect by chemical analysis, has a very determining effect on the size of the grain. These rare elements seem to be very small, they may be very valuable, and it may be very interesting to know them. In that regard, I presume it is to be presumed that the ores from which these irons were made, were the same. If they were not made from the same ores, for instance, one iron having vanadium and the other having none, the result would be questionable.

Then one other point. It seems to be assumed that if these oxides and gases have some effect on the crystallization, that it would be very easy to determine what the gases were by simply making a gas analysis of the iron. That is not necessarily true, because the gases which cause this large crystallization may not be present in the finished iron. A good example of that is in the formation of some strata of granite, very large crystals in the grain, and it has been determined definitely that that was due to the effect of heat, pressure and moisture content, that moisture was present. But when your analysis is made you don't find any moisture in it. So you may have large crystals in your iron, due to some gases or some conditions of gases present in your iron at the time that crystallization has taken place, but none in your finished iron.

R. F. HARRINGTON: Mr. Lowry brought out a point in regard to the micrographs that I don't think should be overlooked. Briefly summarized, on page 492, in reference to the charcoal iron, you get 0.15 depreciation of silicon; on the opposite page, 0.02 increase in the coke iron, on page 494 we get a 0.16 depreciation in the result and 0.07 gained on the coke iron. It occurs to me that that isn't just a coincidence in any sense of the word, and I am wondering if it would be possible to obtain an analysis by sending this material to the Bureau of Standards and determine whether or not this oxygen in question has entered into the matter here, of giving increased strength to these charcoal irons. I don't think that these variations of carbon and silicon, that are quite marked, are a matter of coincidence. I just suggest that possibly the author could submit those samples and we might learn something that could be given out at a later date.

CHAIRMAN H. B. SWAN: I think that is a very good suggestion.

W. E. JOMINY: In answer to the gentleman's question about the effect of the gas, that it may not stay in the metal, the effect of the thing is that when we remelt this metal we get the same result again, which would seem to indicate that the gas does stay in the metal, whatever it is. All the irons given under the list of charcoal irons were made with the same ore, and we did make as thorough an investigation as we could in analyzing one or two samples which showed the greatest difference in strength and tried to determine any particular impurities that might be present in the way of metals, but we were not successful in finding any particular metal that would account for it in any quantity whatever. You see, since they were made from the same ores it is rather to be expected that you would have the same metals in each of those irons, and still you will find there is a wide variation in the strength of those irons. I have been asked by the Bureau of Standards, by Dr. Burgess, to send samples of the irons. He says he has a new method for determining oxygen and he wants to determine the amount of oxygen in the samples.

Notes on Composition and Structure of A. S. T. M. Bar

By J. W. Bolton, Hamilton, Ohio

Part I Introductory

Accurate knowledge of the relationships between the composition of cast irons and their strength is desired by all foundries exercising intelligent metallurgical control of their product. Unfortunately, there are other variables which often mask the real influences of composition. Study of the structure of the metal often explains such seeming discrepancies. In this paper the writer has attempted to show some effects of variation in composition and structure on properties of the standard A. S. T. M. bar. While conditions are different in every shop, it is thought that curves covering the same type mixtures in other shops will probably parallel, if not duplicate, the charts given here.

Some variations which affect results in this type of work are:

(1) Variations in testing due calibration of testing machine, and personal equation of the operators. In these tests the same calibrated machine (a 50,000-pound Riehle) has been used throughout, and the same operators have conducted the tests.

(2) Variations in cupola practice, types iron and coke, make-up of mold, test bar pouring practice, are as slight as is practical since the same general practice was adhered to throughout.

(3) Variations in the type mold and size bar. The bars from which the results were taken were of standard dimensions and were made in oil sand cores with cover cores for the gates.

Notwithstanding these precautions, some variations are unavoidable. The results on silicon and carbon charted are averages

made up from about 1,000 carefully tested bars, a number of which were run in duplicate. The effects of individual variations are minimized by the law of averages.

In addition to the results on silicon and carbon obtained from the regular bars, there are several micrographs and charts covering other properties of the irons. These latter were obtained from some 50 standard test bars (over a couple months' period) and a few exceptionally low and high test bars, all of which were very completely examined by analysis, physical testing, and microscopy.

The foundry of the Niles Tool Works (of the Niles-Bement-Pond Company) is essentially a jobbing shop. It specializes in heavy castings of high quality. Because of its facilities for this type of work, it handles special jobs as well as the regular heavy machine tool line. Since the regular work varies in size from a few pounds to over a hundred thousand, and sections from ½ inch to 5 or 6 inches, several mixtures must be used. For our regular work four mixtures are used, while special mixtures are used for occasional jobs.

The important variables affecting strength of sound bars are graphite, combined carbon, and ferrite. These, in turn, depend largely on the silicon and total carbon. The charts show the effects of these elements, considered singly and together.

Part II Effect of Elements

Silicon.—Decrease of strength with increase in silicon is a phenomenon familiar to all foundrymen. Fig. 1 shows the relation of per cent silicon to the transverse strength, as shown by several commercial foundry mixtures. With the exception of curve No. 3, each curve is free from large jogs. All curves point in the same direction; that is, by straightening the jogs on each curve, we would have four approximately parallel curves. The no steel mixtures, curve No. 4, are the lowest, then the 10 per cent steel mixtures, curve No. 3; then the 20–25 per cent steel mixtures (curve 1) and the highest is the curve No. 2 of the 15 per cent steel mixture. The first inference is that, for the same silicon, 15 per cent steel gives the greatest strength, while

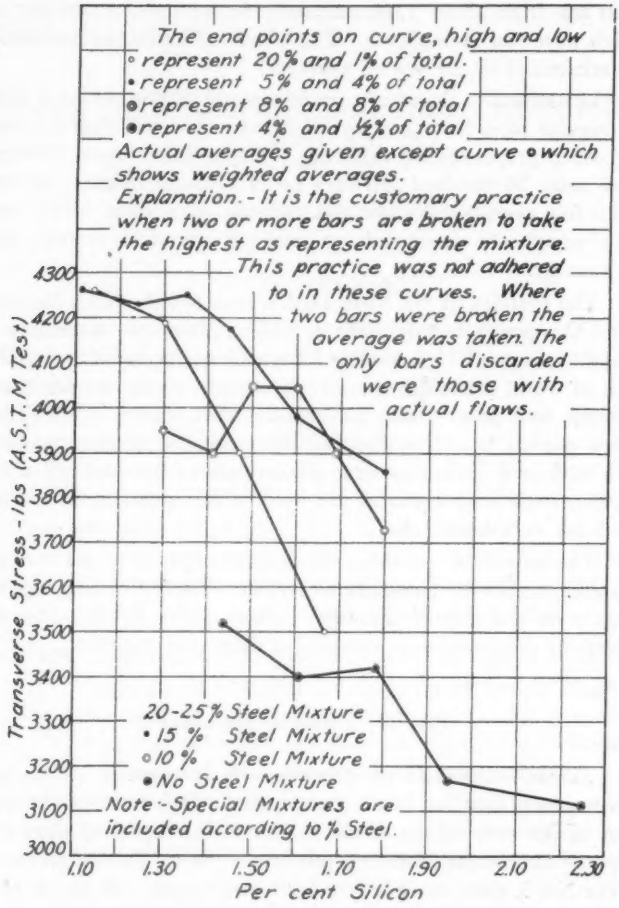

The end points on curve, high and low
represent 20% and 1% of total.
represent 5% and 4% of total
represent 8% and 8% of total
represent 4% and ½% of total
Actual averages given except curve which shows weighted averages.
Explanation.- It is the customary practice when two or more bars are broken to take the highest as representing the mixture.
This practice was not adhered to in these curves. Where two bars were broken the average was taken. The only bars discarded were those with actual flaws.
Transverse Stress - lbs (A.S.T.M Test)
4300
4200
4100
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
3000
20-25% Steel Mixture
15 % Steel Mixture
10 % Steel Mixture
No Steel Mixture
Note - Special Mixtures are included according to % Steel.
1.10
1.30
1.50
1.70
1.90
2.10
2.30
Per cent Silicon

FIG. 1—RELATION PERCENT SILICON TO TRANSVERSE STRENGTH

the no steel mixture is weakest. However, there are other factors which must be considered before drawing such a conclusion.

The effects of the variables of cooling rate, pouring temperature, per cent sulphur and manganese, etc., are minimized by averaging. The variables which are peculiar to the mixtures

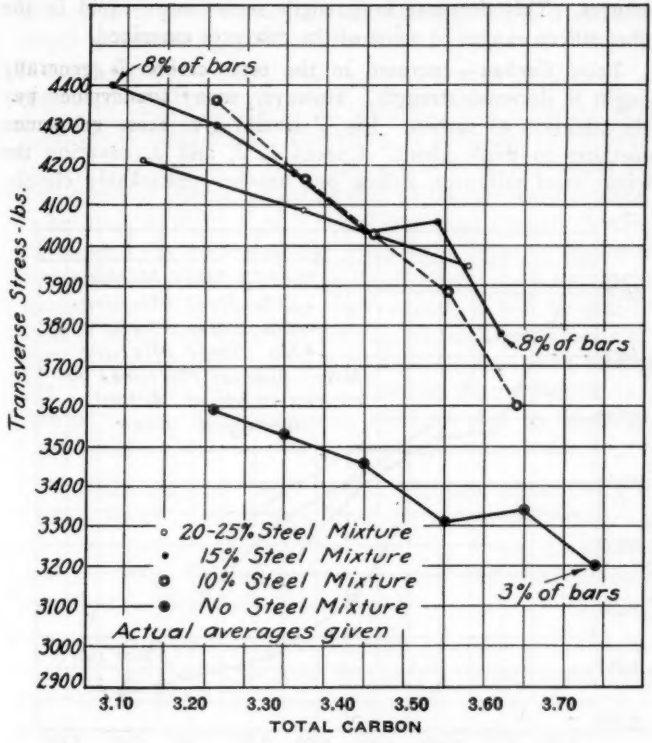


FIG. 2—CURVES SHOWING RELATION OF TRANSVERSE STRENGTH TO TOTAL CARBON PERCENT.

besides silicon, are the per cent carbon and the per cent phosphorus; the more steel the less carbon and phosphorus. The 20–25 per cent steel mixtures normally contain more sulphur, and enough manganese for all of it to form manganese sulphide inclusions.

The only conservative conclusion that we can form is that, for the A. S. T. M. bar equal increase in silicon affects an approximately equal amount of decrease in strength for the different

mixtures. This decrease in strength seems more rapid in the higher silicon ranges of some of the mixtures examined.

Total Carbon.—Increase in the total carbon is generally thought to decrease strength. However, many foundrymen pay little attention to carbon. Fig. 2 should give these gentlemen something to think about. Curves 1, 2, and 3, covering the various steel mixtures, follow one another remarkably closely.

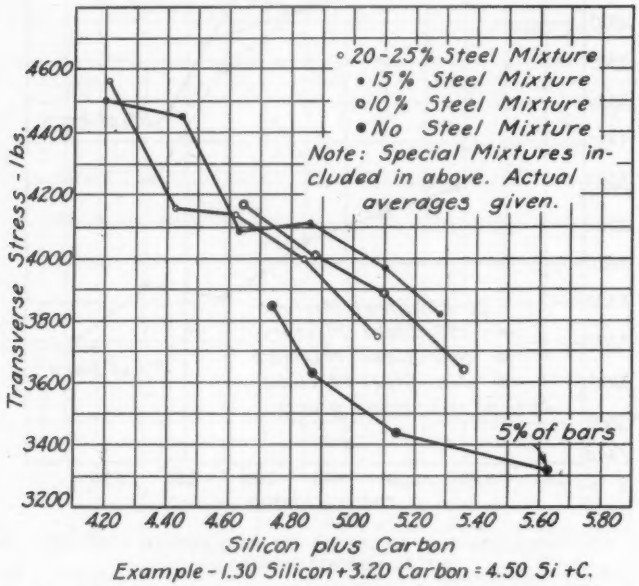


FIG. 3—CURVES SHOWING THE RELATION BETWEEN TRANSVERSE STRENGTH AND THE FACTOR SILICON PERCENT PLUS CARBON PERCENT

The no steel curve No. 4 stands by itself. An averaged curve for the three steel mixtures would enable one to predict the strength for each carbon on each steel mixture. Unfortunately, such an idea, if applied to other mixtures, would lead to grave errors. The *silicon* in these mixtures varies somewhat in the same direction as the carbon. Also, the silicon on the no-steel mixtures will average considerably higher than that on the steel mixtures. On

the mixtures given no rule for calculating strength would seem to apply to all four types of mixtures.

Silicon and Carbon.—We have seen that increase of either silicon or carbon decreases the strength. The influence of these elements is cumulative. Therefore, it is logical to consider the influence of their *sum.* This has been done in Fig. 3 and Fig. 4. The resulting curves, including that of the no-steel mixtures, are closer than those of Figs. 1 and 2, and their general direction is the same. The curves of Fig. 3 led us to construct the average curve, Fig. 4. This curve, in the ranges shown, approaches a straight line. In examining these curves, it will be noted that there is much less variation between various type mixtures; the big gap between the steel and no-steel curves shown in Figs. 1 and 2 is partially bridged. It is apparent that the effect of steel "per se" is less than would seem to be the case on inspection of Figs. 1 and 2.

Silicon and Two Times Carbon.—Critical inspection of Figs. 1 and 2 seems to indicate that carbon exerts more influence than silicon. With this in mind, the chart, Fig. 5, was drawn up. It does not bridge the gap between the steel and no-steel mixtures as well as the Si plus C curves, Fig. 3.

Preliminary Conclusions.—Effects of silicon and total carbon variation have been considered first as it is through these elements that the practical foundryman is best able to *control* the physical properties of his metal. The following preliminary conclusions are justified by the experimental data presented above.

The sum, silicon plus carbon, varies inversely with the transverse test—very closely for various semi steels, and reasonably so for regular cast iron. *This sum gives a more accurate idea of the probable strength of the A. S. T. M. bars than any other simple and inexpensive test.*

Steel seems to exert an effect on strength "per se." The major part of the variations between results on cast irons and semi steels can be explained by various differences in the analyses. Notwithstanding this, there remains a gap which is bridged only by assuming that the steel has some intrinsic merit besides its known effect on composition. The mere addition of steel will not

raise the strength some fifty per cent if the analysis is kept the same—but it apparently raises it 10 per cent. The writer does not believe in mysterious properties. There are some material differences in the manufacture of pig iron in the blast furnace and of steel scrap pig in the cupola.[1] Different processes in iron and steel manufacture give different strengths for the same analysis

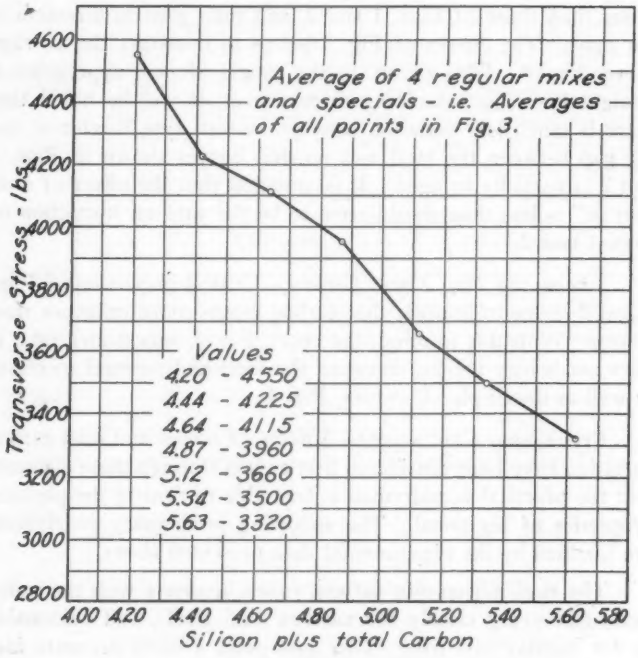


FIG. 4—CURVES MADE FROM DATA OF FIG. 3.

and many of these process effects have been explained in a satisfactory manner.

Total carbon seems to exert a greater influence on the strength of the A. S. T. M. bar than silicon; per cent variation for per cent variation, and in the ranges given.

[1]The writer has explained his theory of this in Foundry, Sept. 1, 1923, p. 701.

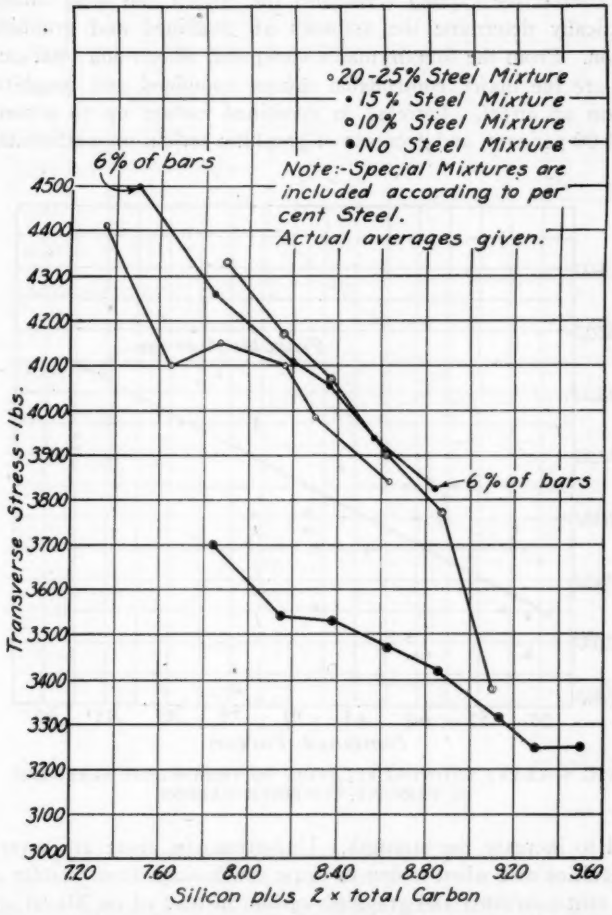


FIG. 5—CURVES SHOWING RELATION OF TRANSVERSE STRENGTH TO THE FACTOR PERCENT SILICON PLUS 2 TIMES THE TOTAL CARBON PERCENT.

Combined Carbon and Graphite

Under like cooling conditions the silicon and total carbon practically determine the amounts of combined and graphitic carbon. From the foundryman's viewpoint, silicon and total carbon are the major controllable causes, combined and graphitic carbon an effect. Increase in combined carbon up to around .70–1.00 per cent, and decrease of graphitic carbon unquestionably

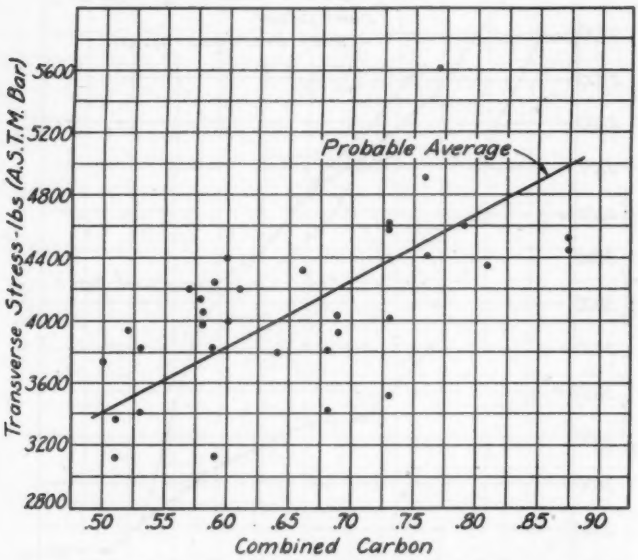


FIG. 6—CURVE SHOWING RELATION OF TRANSVERSE STRENGTH TO PERCENT COMBINED CARBON.

tend to increase the strength. Unfortunately, there are several difficulties met when trying to draw conclusions from results on per cent combined and graphitic carbon instead of on silicon and total carbon. First, speaking of the A. S. T. M. bar, there is no vast difference encountered in per cent combined carbon of bars of considerable variation in strength. The best methof of analysis[2]

[2]Subtracting graphitic from total carbon.

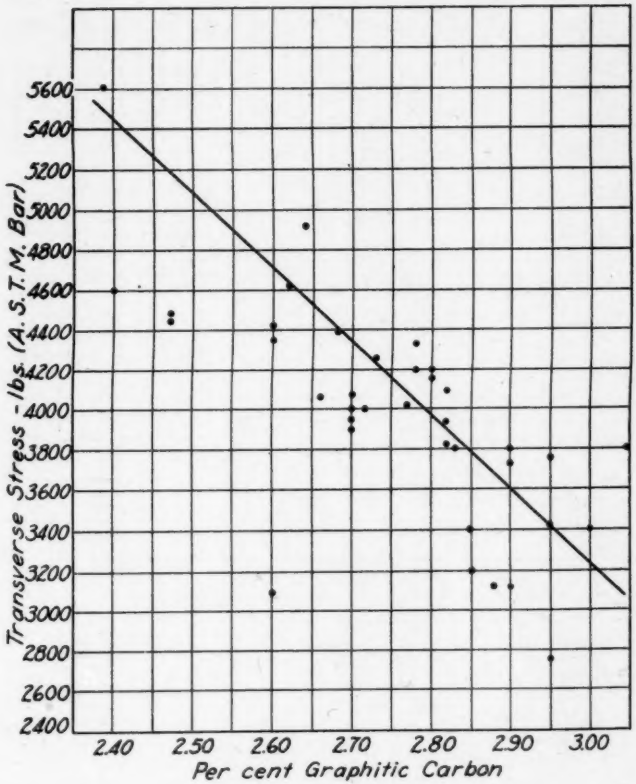


FIG. 7—CURVE SHOWING RELATION OF TRANSVERSE STRENGTH TO PER CENT GRAPHITIC CARBON.

is subject to cumulative error. Sampling, even in the A. S. T. M. bar, must be done very carefully to get representative drillings, for the outer part of the bar contains a different amount of combined carbon than the inner portion. Then, in case of graphitic carbon, the size and distribution are as important as the amount, if not more so. As the writer will show in the technical supplement, the distribution of graphite in the A. S. T. M. bar is deter-

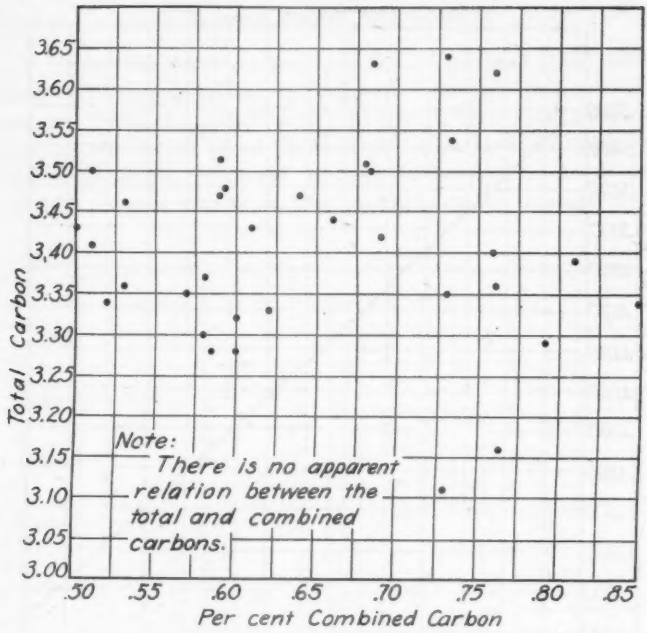


FIG. 8—SHOWING LACK OF RELATION BETWEEN PERCENT COMBINED CARBON AND TOTAL CARBON.

mined largely by the silicon and carbon, making it necessary to know these as well as the per cent graphite.

Notwithstanding these objections, the apparent influence of per cent combined and graphitic carbons deserves consideration. The writer gives, in Fig. 6 and Fig. 7, results obtained from some thirty-five very carefully tested bars.

These charts indicate the increases in strength due increase in combined carbon and decrease in graphite. Mixtures from 0 to 25 per cent steel are listed. The writer thought there might be some relation between the per cent total carbon and the combined carbon. This is evidently untrue for these bars, as is shown by Fig. 8. It must be remembered that increase in combined carbon increases the strength to a *maximum* at .70–1.00 per cent,

from which point the strength falls off *very rapidly*. Decrease in combined carbon results in decrease of strength to a ***minimum***.

Relations Between Transverse and Tensile Strength

Engineering formulae consider cast iron in terms of tensile strength. This is illogical, because cast iron is rarely used in tension. Transverse and compression stresses are the common type stresses. Strength of metal is rarely a factor in design for compressive stresses. Most of the practical loads are transverse, of the cantilever type. The 10–1 ratio is widely used today. It's

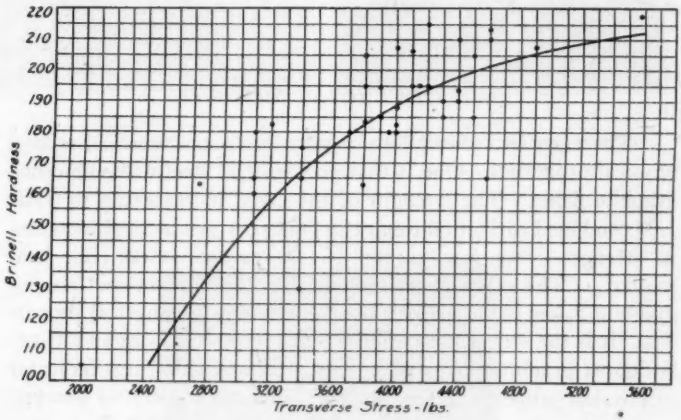


FIG. 9—CURVE SHOWING RELATION BETWEEN BRINELL HARDNESS AND TRANSVERSE STRENGTH.

a mighty convenient ratio—but it isn't accurate! True enough, there are bars with a ratio 12–1, and a number at 10–1, but the majority are lower. The A. T. S. M. sets the ratio 28,000–3,800 or a little less than 7½ to 1. On averages of numbers of bars the writer has found that this ratio is a good one, perhaps a little conservative, but it is better to cheat oneself on the safe side than to claim and not make good. There are many bars that test over 4,500 transverse, but in commercial practice there are comparatively few A. S. T. M. bars much over 40,000 tensile. In experimental work one can get lots better. Comparisons must

be on the *same basis,* the standard A. S. T. M. bar, and stunts mean little in practical work.

Relation Between Brinell Hardness and Transverse Strength

Fig. 9 is a curve showing relation between Brinell hardness and transverse strength.[3] The bars at the lower end of the curve are from centers of 4 to 8 inch diameter bars. From 3,800 up the Brinell seems to increase more slowly with increase in strength. The Brinell follows the amount of combined carbon as seen by the microscope. For ferritic irons, with no combined carbon it is about 100, the Brinell of ferrite. It is 200 for the eutectoid irons, the Brinell for pearlite.

Part III Effect of Structure

There are two conceptions of grey iron's structure and related physical properties. One is that grey iron is[4] steel with enmeshed graphite flakes. The strength of the metal increases up to 0.70–1.00 combined carbon (the entectoid matrix) just as steel increases in strength from low carbon to .90 carbon stock (not heat treated). The other conception is that the amount and size of graphite flakes is the major factor governing the physical properties. It is the writer's experience that the amount, size and distribution of graphite flakes is the best practical structural indicator of physical properties. On the other hand, the amount of pearlite, combined carbon structure, must always be considered.

The metal usually fractures along the planes of the graphite flakes. See Fig. 10. The size and distribution of graphite flakes determine the nature of the fracture and the grain of the iron.

The writer has found that size and amount *alone* do not tell the whole story, especially on the A. S. T. M. bar. In this bar the cooling conditions are such that the flakes have little chance for growth after their primary formation, and the matrix is nearly eutectoid. See Figs. 11 and 12, showing matrix, and Figs. 13, 14,

[3]The Brinell numbers were determined on an American Model Brinell Hardness Tester, using microscope instead of depth gage and 3,000 K. G. load.

Note: Other elements—The effects of phosphorus, sulphur and manganese are discussed in the technical supplement. These elements exerted very little influence on the bars under consideration.

[4]Structurally speaking.

FIG. 10—FRACTURE ALONG GRAPHITE

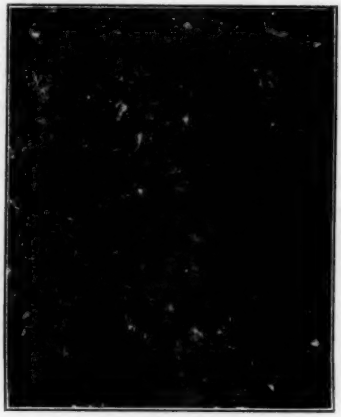


FIG. 11—STRUCTURE SHOWING STRONG MATRIX

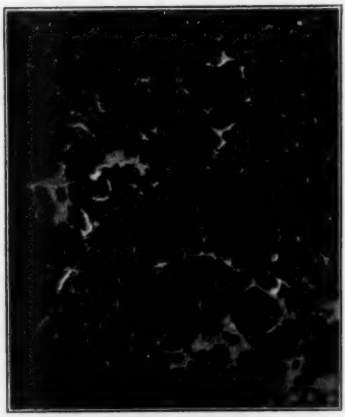
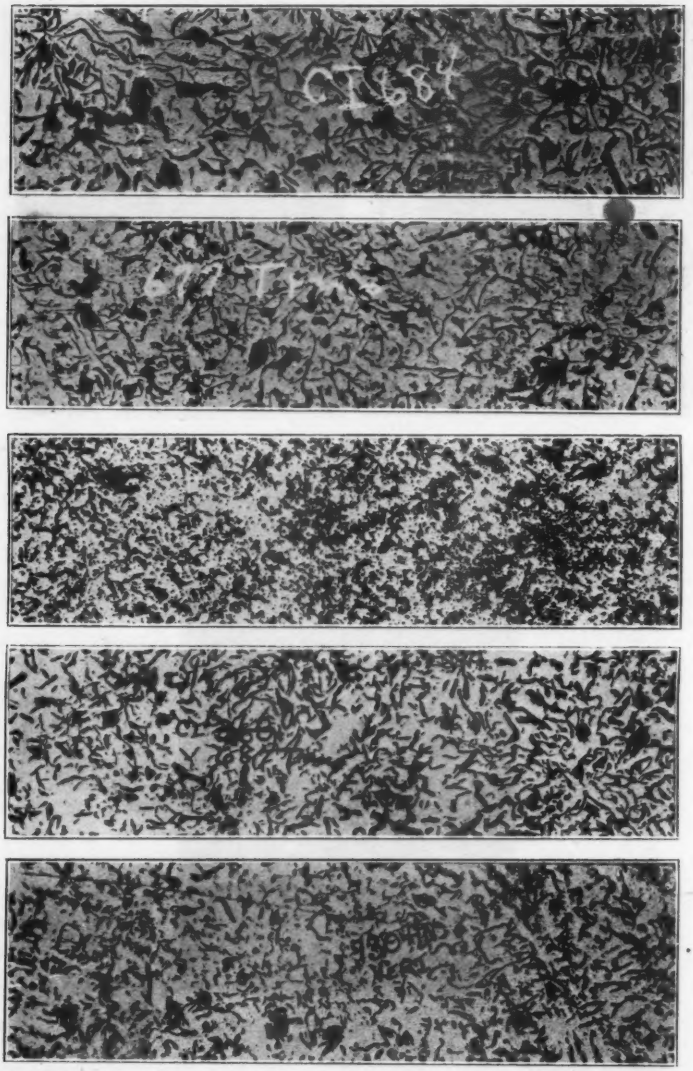


FIG. 12—STRUCTURE SHOWING WEAK MATRIX



FIGS. 13 TO 17—BAR 1, TRANS. 3400 LBS., BRINELL 175, SI+C 5.45; BAR 2, TRANS. 3600 LBS., BRINELL 179, SI+C 5.20; BAR 3, TRANS. 3800 LBS., BRINELL 183, SI+C 5.00; BAR 4, TRANS. 4100 LBS., BRINELL 188, SI+C 4.60; BAR 5, TRANS. 4500 LBS., BRINELL 200, SI+C 4.20.

15, 16 and 17, showing graphite formation. The primary *distribution* of graphite is very important.[5]

Very uniform distribution promotes great strength, although the average size of flake may not be the smallest. This is well shown in Fig. 18, a sample showing great transverse strength and very uniform structure.

The majority of high strength bars have very fine graphite, some of it occurring in dendritic formations. (Fig. 19.)

Lower test bars often show whorl formations, as shown in Fig. 20. These whorls in the A. S. T. M. bar are largely a primary formation, as explained in the technical supplement. The flakes are coarser and bunched.

Very large flakes indicate slow cooling and are not found in regular A. S. T. M. bars. See Fig. 21. These are accompanied by low pearlite, as in Fig. 22.

Conclusions

Graphite distribution is an important factor in determining the strength of the A. S. T. M. bar. Size, amount and distribution are factors which are very intimately linked. Distribution is most easily judged under the microscope and is the most significant structural detail of the A. S. T. M. bar. Study of distribution must be done at low power magnification so that a representative area can be shown. Most high test irons show dendritic segregations, while low test irons have whorl formations. If all A. S. T. M. bars were cast at the same temperature[6] into molds of equal heat conductivity, the most important variable would be the composition. In this case the analysis would tell the whole story, i e., it would determine the variations in structure and physical properties. The microscope is of value in that it will indicate abnormalities in cooling rate. The greatest field for the microscope is in examination of irons whose cooling rate is not known, and in research work.

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[5]See Technical Supplement for more complete exposition and for details of microscopic methods.

[6]The writer is talking about variables whose effects are fairly well known. The question of oxidation, of special virtue of certain brands of coke, pig, etc., are in the more theoretical stages.

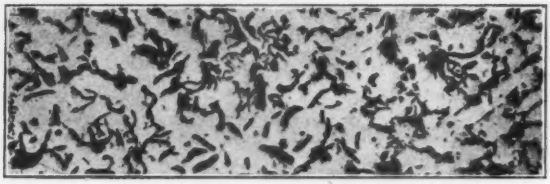


FIG. 18—GRAPHITE OF STRONG IRON

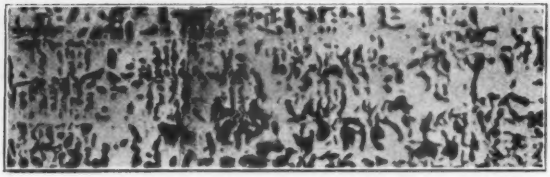


FIG. 19—SHOWS DENDRITIC STRUCTURE

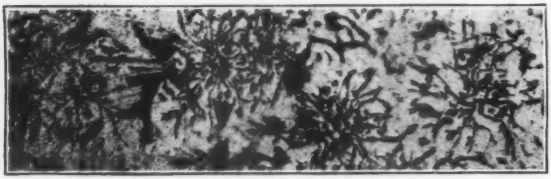
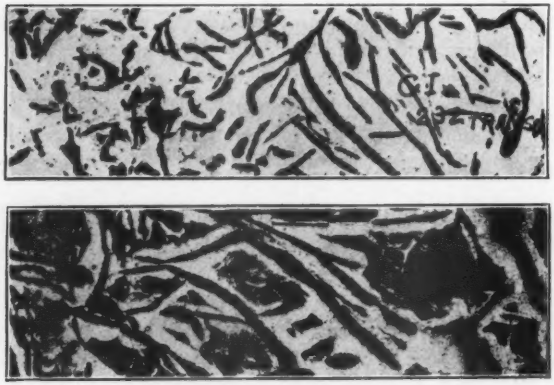
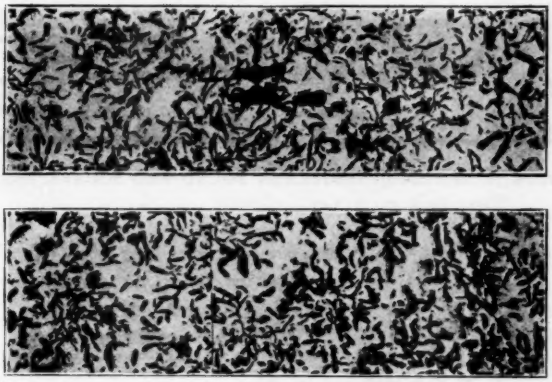


FIG. 20—GRAPHITE OF WHORL STRUCTURE



FIGS. 21 AND 22—STRUCTURES SHOWING LARGE GRAPHITE AND LOW COMBINED CARBON



FIGS. 23 AND 24—UPPER FIGURE SHOWS VERTICAL SECTION AND LOWER FIGURE TRANSVERSE SECTION

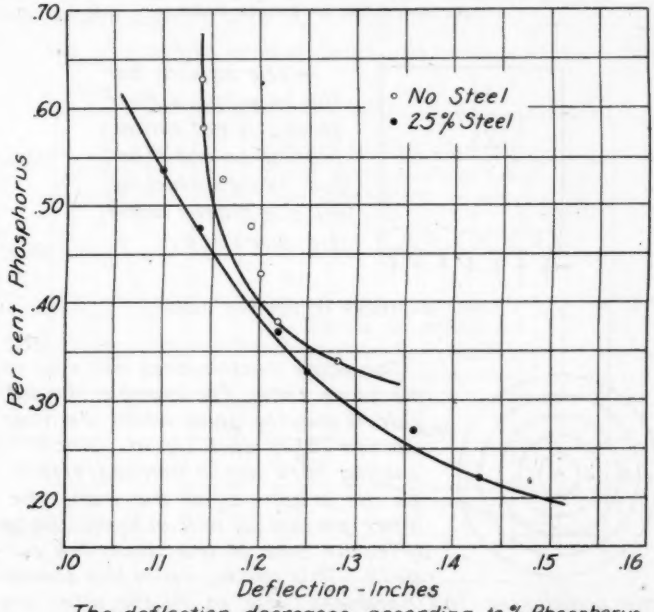
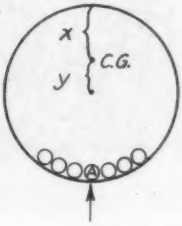


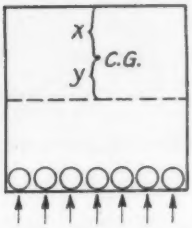
FIG. 25—CURVES SHOWING RELATION OF PER CENT PHOSPHORUS TO DEFLECTION

FIGS. 26 AND 27—DENDRITES IN ROUND AND SQUARE BARS



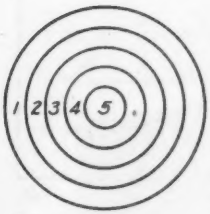
It is obvious that the maximum stress is concentrated on the fiber marked "A".

FIG. 28—FIBERS IN ROUND BARS



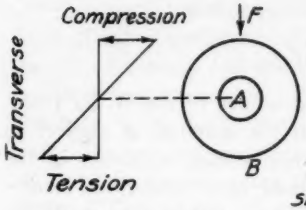
In the square bar the maximum fiber stress is not concentrated on one fiber, but is resisted by all the fibers along the surface.

FIG. 29—FIBERS IN SQUARE BARS



The whole section does not cool at the same rate. For example, the outside (1) may be solid while the inner portion (5) is still liquid. Since cooling rate has a marked effect on the properties of the iron, the inner portion (5) will actually be a different sort of iron than the outside (1). This shows up in the strength the grain size, the hardness, and in all the other engineering properties of grey iron.

FIG. 30—CONCENTRIC COOLING



In the transverse test the stress at the neutral axis "A" is zero, increasing to a maximum tensile stress at the ultimate fiber "B". Thus the transverse tests measure the strength of the outer part of the bar, shown ring 1 in figure 31.

In the tensile bar, however, we are really measuring the strength of the inner portion "A". This, as shown in fig. 31, is an entirely different iron than that of the outside of the bar. This difference is most pronounced in bars of large diameter, since there is greater variation in the cooling rate of the inner and outer sections of the bar.

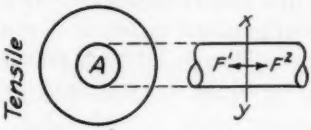


FIG. 31—STRESSES IN TRANSVERSE AND TENSILE TESTS

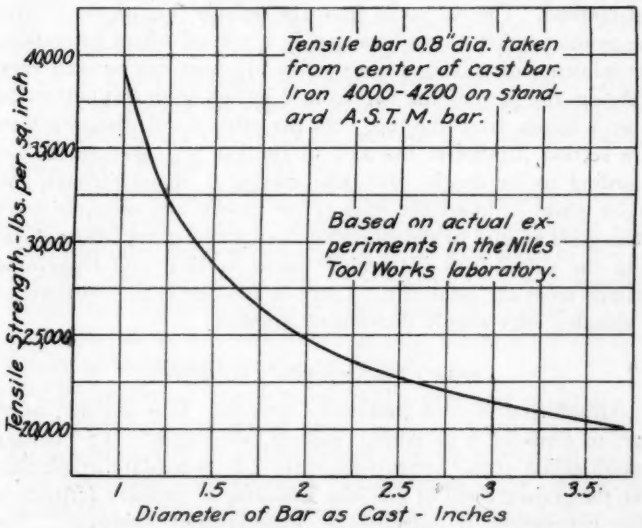


FIG. 32—LOSS IN STRENGTH DUE TO SECTION SIZE

Part IV Technical Supplement

Macroscopic Methods

Study of the composition and structure of the A. S. T. M. bar is complicated by the fact that the material is subject to considerable segregation. This is not always apparent in the ordinary analytical and microscopic tests, but is evident on macroscopic examination. For this reason it is necessary to study the macrostructure. Macrostructure is the structure apparent to the eye or on low magnification*. Cast iron freezes selectively. As a result of this, there are segregations of graphitic carbon as shown in Fig. 19. These, of course, have considerable influence on the strength. Macroscopic methods also reveal the distribution of the phosphorus network.

Section Examined

In ordinary macroscopic and microscopic tests on the A. S. T. M. bar the natural tendency is to examine a section vertical to the axis of the bar. This, in the author's experience, is the best method. The bar cools from the outside toward the center. The primary crystals are arranged in a sort of wheel formation. The influence of cooling from outside to center can be seen very nicely on any part of the bar from 2 inches from the bottom to about 4 inches from the top. On the other hand, the structure on a section parallel to the axis of the bar will vary somewhat according to its depth. It's like cutting a chord through the wagon wheel—you see the ends of the spokes, and certainly don't get as good an idea of the wheel as when viewing the whole wheel from the side. Figs. 23 and 24 show vertical and transverse sections from the same bar. There is apparently little difference in samples with evenly distributed graphite.

Primary and Secondary Graphite

Graphitization is a continuous process. It is simpler, however, to consider it as taking place in two stages: (1) Primary graphitization of the cementite forms; (2) Secondary graphitization, the grain growth of graphite following its primary formation. This conception is justified by experimental evidence. The

*J. W. Bolton, *Study Structure of Gray Iron*, The Foundry, vol. 52, pp. 628-634, Aug. 15, 1924.

author has shown that the first formed graphite follows the outlines of the cementite formations. While these primary groups do not completely lose their identity, their graphite flakes grow and rearrange themselves. Due to the relatively rapid cooling of the A. S. T. M. bar, there is little time for secondary graphitization. The primary graphitization depends largely upon the analysis and the rate of cooling through the range that cementite separates. The author has explained these effects in detail in an article to appear in Iron Age.

Other Elements

In the first parts of this article the author gave in detail results showing effects of variations in silicon and the various carbon forms. There are three other elements commonly found in cast iron, namely, manganese, sulphur and phosphorus. As explained above, variations in these elements probably had very little effect on the curves given. We have heard a great deal about the effects of sulphur, and the sulphur manganese ratio. In the ranges 0.07 to 0.15 sulphur and 0.35 to 0.80 manganese, the author has not observed any marked effects, bad or good, traceable to these elements. Medium sulphur (0.10–0.15) tends to close the grain in heavy sections, which is a well known fact. Sulphur used to be blamed for most blowholes, probably because the blowholes, seeking the top, occur on the cope side, and the sulphides, being light, float to the top, too.

Sulphur certainly does not form weak networks in ordinary irons. Manganese and the manganese sulphur ratio in the ranges indicated don't seem to have much to do with most of the engineering properties of the iron. Of course, very low manganese metal from higher manganese irons indicates oxidation, as does excessive silicon loss, high iron slag, etc. High manganese is well known to increase the combined carbon.

Phosphorus is usually considered a promoter of fluidity, and many looked with disfavor upon the low phosphorus irons. In the ranges from 0.20 to 0.80 phosphorus, the writer has observed little difference in the foundry. Temperature is the biggest factor in fluidity. Many who formerly used medium high phosphorus iron pour low phos iron into thin sections with success. On the

other hand, phosphorus is a hardener, not necessarily apparent in a test like the Brinell test, but it is an abrasive hardener.[8]

The most pronounced effect of phosphorus on the A. S. T. M. bar is its effect on deflections, as shown in the diagram, Fig. 25. It apparently does not have much influence on strength.

Structure and Shape of Bar

The crystallization of cast iron starts on the outside of the casting and runs toward the center. Refer to Figs. 26 and 27. In a transverse test on any round bar comparatively few "fibers" receive the maximum stress. Refer to Figs. 28 and 29. On a square bar, however, there are a number of "fibers" which receive the stress at the same time, hence the square bar will resist a transverse test better. Engineers take this fact into account in formulas for section moduli. The 1.25 inch diameter bar of the A. S. T. M. standard is 1.227 square inches in area and 3.927 inches in circumferences. A square bar the same area (1.227 square inches) as the A. S. T. M. bar has sides 1.108 inches, and a periphery of 4.432 inches. From this we see that area for area the square bar has two advantages. First, because of its greater periphery, cooling takes place over greater area. More rapid cooling results in smaller grain and greater strength.[9] Second, the section modulus favors the square bar.[10]

$$\frac{X^3}{6} = \frac{1.108^3}{6} = .226 \text{ (square bar)}$$

$$\frac{A}{4}r = \frac{1.227 \times .625}{4} = .192 \text{ (round bar)}$$

These differences are apparent in actual practice.[11] Cast iron does not come up to all the requirements for application of the section modulus law. The flat surfaces are rarely truly parallel and straight, the knife edges rarely are in exact alignment, the material is not homogeneous, etc.

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[8] *Foundry*, Aug. 15 and Sept. 1, 1923, and *Iron Age*, Annual Review No. Jan. 1924.

[9] If there is not too much chilling.

[10] Assuming that the material is homogeneous and in other ways conforms to the requirements for application of the formula.

[11] The writer showed this in a series of experiments on different shapes and sizes, in 1921.

We have seen how, due to structures formed in cooling, the round bar is more uniform than the square.[12] The round bar also seems to be the one giving the most accurate measure of the ultimate fiber stress—the property of cast iron which is really of most interest to engineers. For these reasons the writer is inclined to favor the round bar for testing work.

Transverse and Tensile

Castings rarely break due to true tension stresses. The usual stresses are of the cantilever type. Nevertheless, nearly all engineering formulae use tensile strength. Most tests of cast iron are transverse. The difficulty of getting proper results from the tensile strength are well known. All ratios of tensile to transverse are arbitrary. There is no logical connection, as *two different irons* are being tested. Fig. 30 shows how the physical properties change gradually from the outside to the center. In the transverse test it is the stronger outer "fibers" which are stressed. In the tensile test, the weaker center structure is stressed. The diagram, Fig. 31, illustrates these stresses. In smaller bars the cooling is more nearly uniform and the differences are not so extreme between the outer and inner portions. In a very large bar the outside may be fairly strong and the inner portion very weak. The A. S. T. M. bar is large enough so that many irons show considerable difference between their outer and inner structure.

Size of Test Bar

The standard A. S. T. M. test calls for a 1.25 inch diameter bar. The author has at hand a considerable amount of data on the 1, 1⅛, 1⅜ and 2-inch sizes. He will limit himself to a few general observations, to avoid overburdening an already lengthy discussion.

The smaller bars undoubtedly have better structure, provided silicon is high enough to avoid excessive chilling. This difference is very apparent in the tensile test. Iron giving a bar of 4,000 pounds *standard* transverse test will give about 40,000 pounds tensile if cast into 1-inch bars. The tensile test is sensitive even

[12]Sharp corners are always sources of weak structures. This is seen in heat treating, in ingot making, in casting practice and in all places where metals are cast or fabricated.

to the slightest variations in section size. A 1-inch bar which gives, say 40,000 tensile will give 33,000 to 36,000 in the 1¼-inch diameter bar, about 30,000 to 32,000 in the 1⅜-inch diameter bar and 24,000 to 26,000 in a 2-inch bar.[13] A 4,000-pound standard transverse bar is approximately equivalent to a 16,000-pound 2-inch diameter transverse bar. The respective areas are 1.227 and 3.142 square inches (radii .625 and 1 inch). Section moduli $\frac{Ar}{4}$ or $\frac{\pi r^3}{4}$ in the ratio:

$$\frac{(.625)^3}{1^3} = \frac{.244}{1} \text{ or about 1 to 4}$$

This is the same ratio as the actual tests. Therefore, to get good looking results, it is best to make small tensile bars and large transverse bars. It is obvious that transverse tests cannot be converted area for area, as is sometimes done.

The writer has at hand analytical summaries for about three hundred 1⅜-inch diameter bars and one hundred and twenty-five 2-inch bars. The results, from a qualitative viewpoint, are similar to those given in part II of this paper. However, the slower cooling rate has its effect and the bars seem more sensitive to changes in pouring temperature.[14]

What test bar is most practical? The author feels that until a very great deal more research data is available it is best to stick to the present standard bar. Smaller bars do not seem to show the effects of the elements as well. Larger bars depend more on pouring temperature. *Research and practical experience determine the relation* of the bars to the castings. Tying a coupon on the casting and other subterfuges are rarely satisfactory.

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[13]This is assuming, of course, that the tensile test bars are of the standard dimensions, cut out of the *centers* of the respective bars.

[14]In bars 4 inches to 8 inches diameter, the pouring temperatures have a very great influence indeed!

Notes on Illustration of Composition and Structure of A. S. T. M. Bar

Note on Fig. 10—Fracture usually occurs along the graphite flakes. This is shown very clearly in this micrograph. The black space is the fracture. The graphite shows up as thread-like indentations. Examination of the edge of the fracture shows that the break follows the flakes. Study of the graphite flakes is very important, since they play so large a part in determining the strength and finish of the iron. About 10 diameters, unetched.

Note on Fig. 11—Etched structure of a strong iron. All the components seem very uniformly distributed. Note the absence of phosphide network structure, claimed by some to be an essential for producing a strong iron. Tensile strength 41,030 lbs., Brinell 217. 100 diameters, etchant picric acid.

Note on Fig. 12—Etched structure of a weaker iron. There is some slight segregation of steadite, but all in all the structure is fairly uniform. The etched samples do not show the differences as well as unetched samples. In the A. S. T. M. bar most irons appear of nearly eutectoid composition. Tensile strength 25,130. 100 diameters etchant, picric acid.

Note on Fig. 18—Unetched structure of a very strong bar. Note the very uniform distribution of graphite. Analysis shows that the percent graphite is low and that the matrix is eutectoid. Transverse (A. S. T. M. bar) 5610 lbs. 50 diameters, unetched.

Note on Fig. 19—This micrograph shows a dendritic segregation of graphite. This formation is indirectly due the crystallization of prima austentite. It therefore denotes an iron rather low in total carbon. If the dendrites are small and the graphite flakes fine, the iron has been rather quickly cooled and is low in carbon. We therefore can expect such an iron to be fairly high in strength, nothwithstanding its uneven structure. On the other hand, if the dendrites are large and the flakes coarse, the metal will be medium or low in strength. Tensile 38,070. 75 diameters, unetched.

Note on Fig. 20—The whorl formation shown in the accompanying micrograph is commonly found in A. S. T. M. bars rather high in total carbon. It is the author's experience that such whorls come from ledeburite groups. Such bars (like Fig. 16, for example) may have these groups in very fine formations and be fairly strong. However, if there has been time for growth, the strength is much lower. 75 diameters, unetched.

Note on Fig. 21—A weak iron, unetched, showing large graphite flakes. Such coarse structures indicate slow cooling and are not found in ordinary A. S. T. M. bars. 50 diameters, unetched.

Note on Fig. 22—A weak iron etched. Note the large amount of ferrite and the coarse graphite flakes. Such structures are found in heavy sections made of weak iron. 50 diameters, etchant picric acid.

Discussion—Notes on Composition and Structure of A. S. T. M. Bars

By JOHN SHAW, Sheffield, England.

Mr. Bolton's work always commands thought and can generally be perused with profit. In the present instance, however, while a good deal of work has been put into the paper, so little definite information has been given that the figures given are of little value. In Fig. 1 no total carbon or other constituents are stated. That silicon up to a point opens the structure of an iron by its action on the total carbon has been known for the last 40 years. Its decreasing influence with lower total carbon present is not as well understood. For instance, recently on a downgate 1¼ inch diameter from a semi-steel casting the silicon was 3.06 per cent with the total carbon 2.98 per cent. The tensile from this gate turned down to .8 inch in the center gave over 18 tons per square inch.

Referring to tables 2, 3, 4 and 5 one cannot make any comparison with our practice. You can only surmise that you have at the starting point of each graph 1.10 per cent silicon, with 3.05 per cent total carbon, climbing up, with an increase of both Si. and C. to 2.3 per cent Si. and 3.65 per cent C. How is it possible to arrive at any conclusions when neither of your main constituents are stationary?

With most of the general conclusions I agree. Several do not coincide with our experiments. I have given an instance where increase of Si. when not considered in conjunction with lower total carbon does not show a lower strength. I agree that after a certain point, increase of either Si. or total carbon decreases the strength, but it does not follow that the sum of the two will always give even approximately the same strength, even when the conditions and other constituents are the same.

There is no doubt steel additions give a more finely divided graphitic carbon. This, together with the difference in analysis,

accounts for the increased strength. Whether this is due to oxygen or other gases, as recent German work would tend to show, is an open question.

Coming now to Figs. 6, 7 and 8, there are two fundamental facts stated on pages 520 and 521 that govern the whole test-bar question, viz.: "That increase in combined carbon increases the strength to a maximum at .7 to 1.00 per cent, from which point the *strength falls off very rapidly*. Decrease in combined carbon results in decrease of strength to a minimum."

That means in nearly all Diesel liners, liners for large marine or land engines, hydraulic cylinders, to mention only three types of castings, the arbitration bar would contain about 2 per cent combined carbon if suitable metal was used, therefore a reduced load on the arbitration bar and not an increase as in the present A. F. A. specification.

Turning now to Figs. 6, 7 and 8, there is no means of arriving at the total carbon of any tests. You may, by taking the highest test of 5,600 pounds, arrive at a figure of (2.38 per cent plus .7 per cent) 3.15 per cent total carbon. That test is represented quite low in Fig. 8. In short, how any conclusions can be drawn, except by those who are in possession of the whole facts, I fail to see. Mr. Bolton's statement that "The primary distribution of graphite is very important," is one reason why irons with the same graphitic and combined carbon fail to give the same test, other conditions being equal.

I agree that the transverse is the most suitable test for cast iron. If the breaking load was also stated in terms of the "Modulus of Rupture" engineers would find it quite convenient. With his conception that the amount and size of the graphitic flakes is the major factor governing the physical properties, when coupled with his later statement, I am in agreement, but he does not tell us how he obtains this control. Seeing the structure under a microscope may show where the weakness is, but does not state the remedy.

Referring to part IV of this paper, if Mr. Bolton has not observed any marked effects of S. or Mn., either good or bad, perhaps he will tell us why a mixture containing .07 per cent S. and .8 per cent Mn. that shows a chill of 1⅞ inch on a rapid

chill test will only show ¾ inch on the roll from this metal, while an iron containing .15 per cent S. and .3 per cent Mn. showing 1⅞ inch chill on the rapid test will show 1⅝ inch on the roll, no appreciable loss of either S. or Mn. being observed when both the rapid tests and turnings from the rolls were analyzed. After all a chill test is the best test of structure. These variations are used purposely to obtain certain definite properties.

We find that influence of P. extends to the transverse test as well as the deflection, but does not affect the tensile test.

Coming now to the final point, in view of his previous conclusions I am utterly at a loss to understand his attitude with regard to the size of bar. It would seem to obtain a strong test bar is of more importance than a strong casting. He shows clearly that an iron that will give 40,000 pounds on an inch diameter bar, falls to 25,000 pounds on a 2-inch bar reduced to .8 inch in the center, if cast from the metal suitable for 1-inch thick castings. If he will use a metal suitable for a 2-inch casting and over for his bars, turning his 2-inch bar down to 1.785 inch in the center he will find his results reversed, as he himself proves earlier on in the paper. If your casting has to be 2-inch average thickness or over, then make your bar about the same section as your casting, so that at all events if cast at the same temperature and conditions, some idea of the metal going into the casting will be obtained. There are snags enough without making any.

AUTHOR'S REPLY:

In his discussion Mr. Shaw has fallen into some errors which are obvious to the careful reader. These are non-constructive criticism, misconception of the aim of the paper, misconstruction of several statements, and irrelevant comment. I will comment briefly upon an example of each.

In no place in his discussion is there any actual refutation of any of the statements, charts or micrographs I gave—either through reference to work of his own or to that of others. He calls attention to the decreasing effect of silicon in presence of lower total carbon. We, too, have seen specific instances of this.

He would jump to a general conclusion, the basis being a few isolated examples—surely unscientific! The curves are based on averages and the limitations of both data given and conclusions reached are quite freely stated.

The paper was written for foundrymen and is not an exposition of any particular unit research problem. The paper covers quite a bit of ground and involved a great deal of work. The intention was to give the practical man a more definite idea of the effects of some of the elements, particularly carbon, upon bars made under commercial conditions, and, through other data given, to make more clear some of the relationships between the bars and castings. The author explained this in the abstract delivered on the convention floor. Mr. Shaw fails to recognize this general attempt, but confines himself to complaint of lack of detailed information in some parts of the paper. If a paper was presented of some 15,000 more words (i. e., complete data from some 1,050 tests plus about 500 supplementary tests) it might prove fatal—and expensive. And who would read such a paper?

He intimates that it is stated that sulphur or manganese exert no effects on cast iron. Where? I state that in ordinary castings in the ordinary ranges the effects are not marked. There has been a great tendency to overexaggerate the influence of sulphur, and too little recognition of the importance of carbon. This is to be deplored. In this country we have the sulphur network theory and in England they have the phosphorus network theory of cast iron fracture. Such misleading ideas are very harmful, preventing sound development through exaggeration of minor details. Work here has shown that in ordinary grey irons the fractures follow the graphite flakes. (See micrograph No. 13, first published in Foundry Aug. 15, 1924.) In other papers it it shown that strong irons do not necessarily have a phosphorus rich network. (Foundry Oct. 1, 1922), that graphite segregations are determined by the analysis as well as by the cooling rate, following the outlines of the potential cementitic areas (Foundry Aug. 15, 1923) and that the individual flake size is no more important than the segregations (Iron Age, Sept. 18, 1924). Any of these papers disprove Mr. Shaw's contentions that the effects of other elements are overlooked. I merely seek to retain

a proper balance in exposition. Mr. Shaw says "there is no doubt that steel additions give a more finely divided graphite flake." This is not necessarily so and finely divided graphite segregated does not give as much strength as uniform medium graphite. Mr. Shaw remembers size and amount, but forgets distribution.

Assertions like that in the latter part of the eighth paragraph of Mr. Shaw's discussion are irrelevant. I have seen too many mistakes resulting from long distance diagnosis harmful to both foundrymen and metallurgists. Cast iron is a complex material and none of us knows all about it.

It is possible to go through the whole discussion showing in detail that in the facts he presents there is no essential difference in his ideas and mine with but one exception. This is the question of the test bar. In this connection I have urged conservatism in changing standards without sufficient data to warrant it. Who really disagrees with this? Different sizes of test bars do not show all we want to know about the castings—this is shown clearly in the paper. We can't get away from practical common sense if we want practical results—the fallacy of different sized bars representing the casting obscures the practical truth.

Discussion—Notes of Comparison and Structure of the A. S. T. M. Bar

R. S. MacPherran: I would like to ask Mr. Bolton the effect of the steel mixtures in his figures 1 and 2. The effect of 10 per cent and 15 per cent steel seems to be greater per unit of steel than that of 25 per cent steel. Now, was this due to the lower carbon in these 10 or 15 per cent steels? Ordinarily, when a high steel mixture is run in the heat, enough carbon is picked up from the bed to more than overcome the difference in steel content; so that we often find a 10 per cent steel mixture lower in carbon than a mixture that goes all the way from 25 to 40 per cent steel. Just as Mr. Bolton outlined, it is kind of deceiving to judge the mixture by the silicon content or even by the amount of steel present, because really in any steel mixture it is to be judged by the actual amount of carbon left in the mixture

finally. I read Mr. Aldrich's article twenty years ago on the excess proposition, and was full of curiosity to make the same test. We took 1-inch square bars, 12 inches between supports, and drilled a ⅛-inch hole through the bar a little above the middle of the bar. We broke these brittle bars and the undrilled bars, and found that the hole had no effect on the breaking of the bar whatever. In fact, in some cases the drilled bars broke higher than the undrilled bars.

J. W. BOLTON: I think Mr. MacPherran's point is very well taken and that there isn't so much difference between the 20 per cent steel mixture and 10 per cent, for example. Then, another thing, the 20 per cent steel mixture picks up more sulphur than the other and contains less phosphorous. Now, these results were taken from data that we had on about a thousand bars in regular commercial practice, the average result. There were considerable variations in some of the individual bars. As to that transverse hole through the center, you can take a bar eight inches in diameter, regular shrinkage in the center, that gets practically the same transverse strength that you can with a bar that is sound; but the tensile strength is practically nothing. If you take into consideration the effect of all of the elements, the apparent difference due to the additional steel is made much less; but we have been unable to account for the last 10 or 20 per cent difference of strength. We have never been able to do it by taking into account the effect of analysis or any other effect. I want to call your attention at this time that in the paper by Mr. Grennan of the University of Michigan, he shows the material differences between the manufacture of what would be called synthetic steel and pig iron in the cupola, which we can readily contrast with that obtained in the blast furnace. In a paper by Mr. Jominy he shows the difference between the charcoal irons and the other irons.

The Effect of Chill on Cast Iron

By E. J. Lowry, Chicago, Illinois

Introduction

The subject of chilling molten iron in a mold has been more or less confined to a group of foundrymen classed in what is known as the "Chill Industry."

The conception of chill iron to the worker of molten metal is one which pictures the use of an outside medium in a mold, a "chiller," to produce a white iron or a dense, close grained grey iron casting. The effect of the "chiller" is to conduct the heat rapidly from the molten mass of iron, thus retaining the carbon in varying percentages in the combined state. The combined carbon is somewhat dependent upon the silicon content present in the casting and possibly upon some other chemical elements plus the rate of cooling.

The grey iron foundryman has displayed, to the present time, little or no interest in the chilling of iron. Perhaps this statement should be qualified somewhat because sometimes troubles, such as shrinkage, involve him in the use of a "chiller" of some sort in order to overcome an existing exigency. But it is true that as a whole the chilling of iron has been sadly neglected by all of us. We have unsuspectingly assumed that the chemical elements in cast iron adjust themselves by virtue of its being either soft iron or hard iron. Then, we have let it go at that and worked our way as best we could.

Little has anyone thought that the time of cooling of iron from the casting temperature might effect all the elements in the cast iron; or even effect more than one element, carbon. When a casting is "poured hot," we know that its character is different than when it is "poured cold." We have all been guessing why this is so. We have assumed that it is the effect of the cooling time upon the carbon. We have laid it to the grain growth of the iron itself. But we never have considered the latter in con-

junction with the distribution of the five major elements in the cast iron as a solution to our problem.

It was for this purpose that this investigation of the effect of chill on cast iron was carried on. It is not complete in its fullest detail. But enough data have been accumulated to make the subject of interest to foundrymen and perhaps to incite a fuller investigation.

It must be remembered that the following information entails a perception of hot metal poured into sand molds or into molds made from cast iron or into sand molds containing "chill-

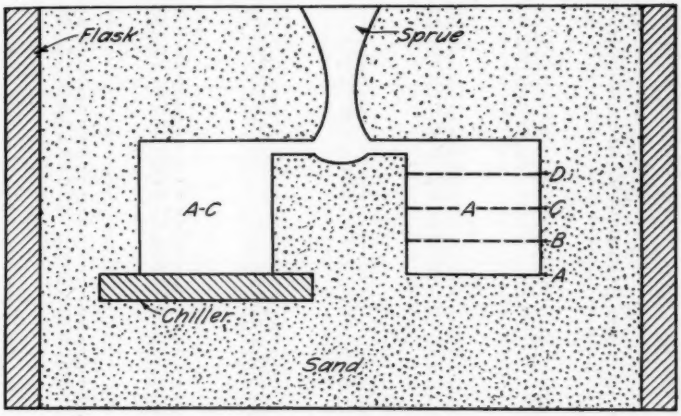


FIG. 1—MOLD ARRANGEMENT USED IN CHILL BLOCK TEST. A, BLOCK WHICH WAS CHILLED; B, BLOCK NOT CHILLED. DIMENSIONS OF BLOCKS 4x4 INCHES AND CHILL 6x6x½ INCHES

ers." Where the average worker of hot metal feels that the peculiarities of a casting are due to its shape, the materials entering its composition and to its analysis, he may be enlightened to find that the pouring temperature and the rate of cooling also greatly influence the properties of a casting.

The Effect of Pouring Temperature and Rate of Cooling

This experiment was performed on 4-inch square blocks arranged as shown in Fig. 1. The data of the test are shown in

Table 1

Specimen No.	Temperature, Degress Fahr.	Total Carbon	Silicon	Sulphur	Phosphorus	Manganese
1-A	2250	3.20	1.52	0.087	0.370	0.42
B	2250	3.12	1.54	0.083	0.370	0.42
C	2250	3.34	1.54	0.079	0.370	0.43
D	2250	3.07	1.53	0.078	0.380	0.42
1-C-A	2250	3.05	1.53	0.077	0.360	0.46
B	2250	2.98	1.47	0.083	0.380	0.43
C	2250	3.02	1.45	0.083	0.360	0.43
D	2250	3.24	1.53	0.088	0.360	0.43
2-A	2425	3.24	1.46	0.080	0.38	0.42
B	2425	3.10	1.51	0.079	0.37	0.43
C	2425	3.26	1.61	0.083	0.38	0.42
D	2425	3.15	1.55	0.079	0.37	0.42
2-C-A	2425	3.02	1.54	0.094	0.370	0.42
B	2425	3.16	1.45	0.088	0.390	0.44
C	2425	3.28	1.47	0.088	0.370	0.43
D	2425	3.30	1.51	0.089	0.370	0.43
3-A	2625	3.26	1.63	0.082	0.390	0.45
B	2625	3.21	1.42	0.075	0.380	0.44
C	2625	3.39	1.44	0.084	0.380	0.42
D	2625	3.15	1.45	0.086	0.380	0.43
3-C-A	2625	3.10	1.59	0.071	0.370	0.45
B	2625	3.29	1.48	0.088	0.390	0.42
C	2625	3.27	1.49	0.090	0.410	0.43
D	2625	3.38	1.46	0.091	0.380	0.43
4-A	2250	3.20	2.02	0.079	0.41	0.49
B	2250	3.02	2.20	0.086	0.38	0.50
C	2250	3.17	2.08	0.084	0.41	0.48
D	2250	3.05	1.89	0.079	0.41	0.49
4-C-A	2250	3.05	1.99	0.093	0.39	0.49
B	2250	3.20	1.96	0.084	0.39	0.46
C	2250	3.07	1.97	0.083	0.40	0.49
D	2250	3.10	1.95	0.083	0.38	0.49
5-A	2425	3.23	1.95	0.077	0.40	0.49
B	2425	3.23	1.97	0.078	0.41	0.48
C	2425	3.08	2.08	0.087	0.40	0.51
D	2425	3.08	2.03	0.092	0.40	0.51
5-C-A	2425	3.07	1.90	0.093	0.39	0.51
B	2425	3.14	2.06	0.084	0.39	0.50
C	2425	3.23	2.01	0.086	0.42	0.50
D	2425	3.12	2.02	0.089	0.41	0.51
6-A	2625	3.19	2.10	0.082	0.42	0.51
B	2625	3.10	1.98	0.078	0.39	0.50
C	2625	3.15	2.04	0.082	0.392	0.48
D	2625	3.09	2.00	0.088	0.394	0.50
6-C-A	2625	3.01	2.12	0.078	0.398	0.51
B	2625	3.14	2.04	0.090	0.400	0.49
C	2625	3.18	2.00	0.088	0.400	0.50
D	2625	3.20	2.06	0.092	0.396	0.50

Table 1, and Charts 1 and 2. The results are perhaps obvious by comparison.

The chemical analysis was performed upon "planings" taken along the chill and then one inch successively back of the chill. The lines from which the planing tool cut these samples are represented in Fig. 1 by the dotted lines shown on block "A."

Referring to charts 1 and 2, it becomes immediately obvious that the chemical elements are not uniformly distributed throughout the blocks. What is more, the deposition of these elements varies with the casting temperature and the rates of cooling.

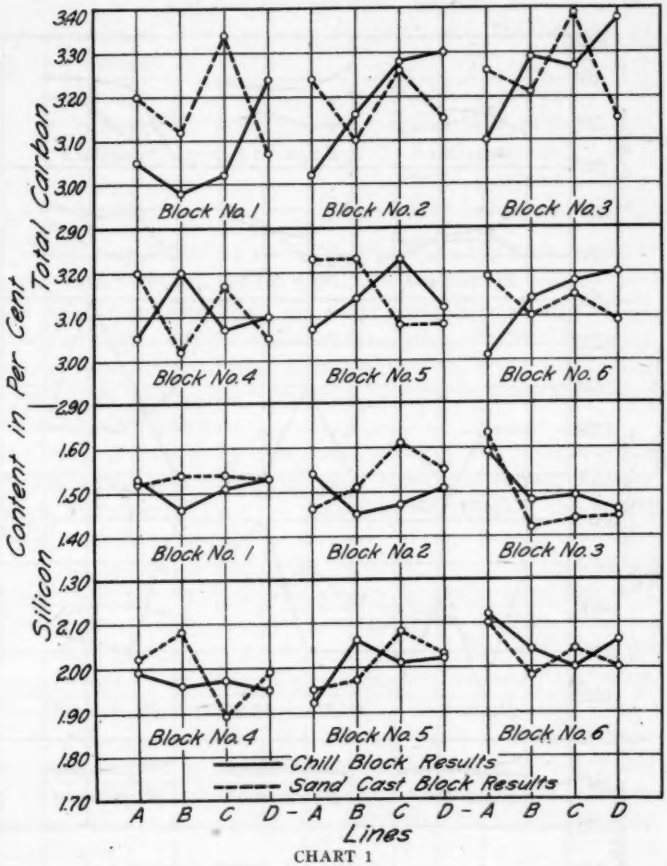


CHART 1

Blocks 1, 2 and 3 were cast from the same ladle of metal, only varying the pouring temperature. The analysis of the heat showed:

Carbon	3.20	per cent
Silicon	1.51	per cent
Sulphur	0.084	per cent
Phosphorus	0.372	per cent
Manganese	0.42	per cent

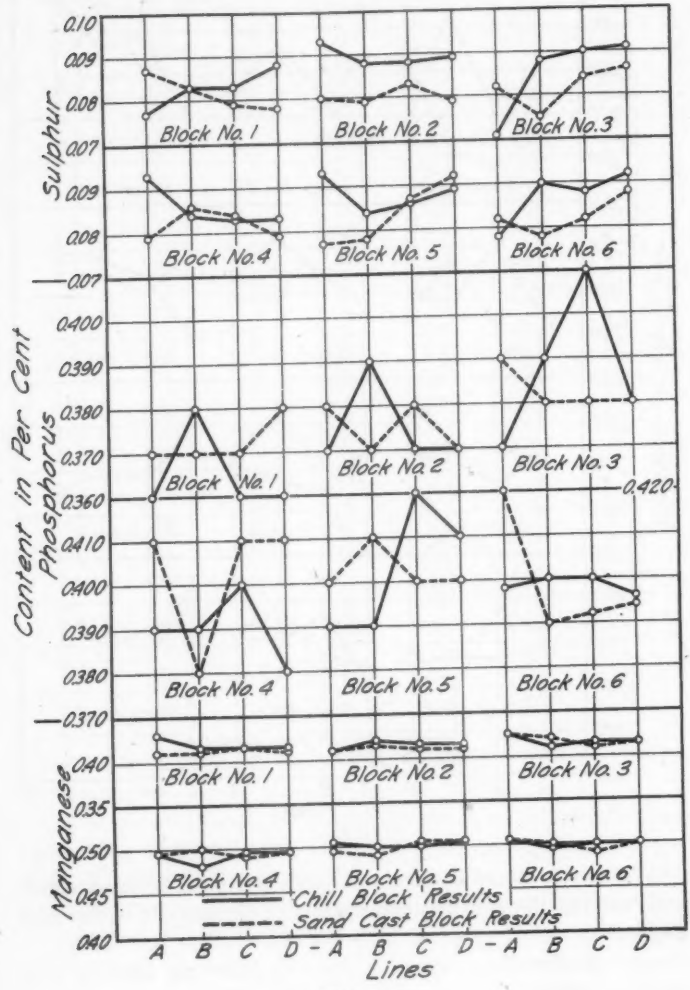

Content in Per Cent
Sulphur
Phosphorus
Manganese
Block No. 1
Block No. 2
Block No. 3
Block No. 4
Block No. 5
Block No. 6
0.10
0.09
0.08
0.07
0.400
0.390
0.380
0.370
0.360
0.410
0.420
0.40
0.35
0.50
0.45
0.040
Chill Block Results
Sand Cast Block Results
A B C D - A B C D - A B C D
Lines

CHART 2

Blocks 4, 5 and 6 were cast from another ladle of metal, with a variation in the pouring temperature. The analysis of this heat showed:

Carbon	3.15	per cent
Silicon	2.01	per cent
Sulphur	0.091	per cent
Phosphorus	0.415	per cent
Manganese	0.51	per cent

When one considers these "heat analyses" and then reflects on the variations throughout the blocks (Charts 1 and 2) perhaps the present idea that "the shape and material entering" a casting's troubles will be somewhat dissipated. Further, they may help to solve some of the chemist's troubles, who continually reports "that the analysis is all right. It must be something else," when bad castings appear.

These graphs show that every element but manganese is affected by the rate of cooling. It is interesting to note that the carbon disturbance is not so marked in the cases of the higher silicon irons in comparison to the lower silicon contents. Furthermore, the carbon seems to be rejected from the chill. The carbon determinations, an uncertainty granted, were run with extreme care, and by the Ascorite absorption method. The results must be taken with some degree of caution. But the general tendency of these graphs being approximately the same, the author feels justified in submitting them for study.

In the case of silicon, this element seems to have an inclination to be retained at chill. Paralleling the sand cast blocks of the carbon determinations and silicon analyses, their deposition in this case is more or less affected by the casting temperatures.

Sulphur seems to be rejected from the chill in the low silicon mixtures with the exception of the medium temperature block No. 2. No explanation can be given for this action in this block. In the case of the sand cast blocks, the action of this element is nicely shown.

The chill seems to reject the phosphorus in the iron, whereas the sand cast blocks try to hold this element as uniformly as possible.

Then, of course, the manganese is held fairly uniformly in all cases.

The conclusions which may be drawn are most interesting. First it may be easily said that the chill tries, in its way, to purify the iron by rejecting the impurities; secondly, that the chill retaining a large amount of manganese, in the low silicon mixtures, the manganese is free to act upon the iron and carbon present in this area. The upshot of the last remark may aid the chill roll producers in solving the reason for poor grade rolls resulting from high manganese heats. This industry is greatly troubled by "soft spots" on roll surfaces when high manganese occurs in their iron. This is a result of either the dissolving of the manganese in the iron or the formation of a double carbide of iron, carbon and manganese. These two last powers are given manganese when it does not have sulphur to act upon. The possibilities of the "soft spots" are increased when the chill rejects the sulphur, thus leaving the manganese free to act upon its own intentions.

The third conclusion is that phosphorus, a weakener of iron, is driven to more harmless places. This should be of interest to the chill car wheel builder who finds objections brought to bear on his product because of this element. A chill car wheel is a small sectioned casting, true, but there is an effect upon phosphorus even in this casting and perhaps an argument may be founded for their benefit. The fourth conclusion is that carbon is rejected from the chill. There is no question advanced that a chill may be made strong and yet hard, if the proper carbon is in the iron. It has been definitely proven that the strongest chill is produced in the Austenoidal range of carbon. This should interest not only those chill manufacturers mentioned but also the chill iron mold board and share manufacturers.

Coming back to the low carbon chill iron, the rejection of carbon in this product is equal to the higher carbon irons. Consequently a steel-iron of advanced strength is attained at the surface of the chill, thereby giving a strong coat to retain the weaker center part.

Last but not least, the grey iron foundryman should be interested in these findings due to the effect of chill or rate of

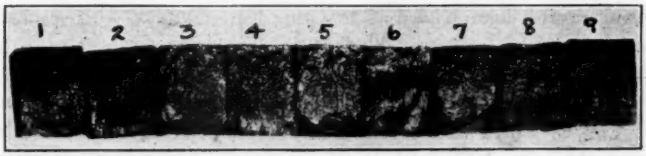


FIG. 2—TEMPERATURE EFFECT ON CHILL METAL WITH SILICON 2.75 PER CENT. POURING TEMPERATURES, DEGREES FAHR.: NO. 1, 2180°; NO. 2, 2225°; NO. 3, 2250°; NO. 4, 2275°; NO. 5, 2300°; NO. 6, 2325°; NO. 7, 2350°; NO. 8, 2375°; No. 9, 2400°

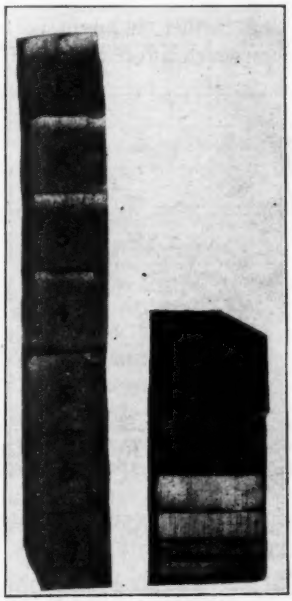


FIG. 3—EFFECT OF VARYING THICKNESS OF CHILLS. TEST BLOCKS SHOWN ON RIGHT AND CHILLS ON THE LEFT. TOP BLOCK NO. 1 CAST AGAINST 3/4-INCH CHILL; NO. 2 AGAINST 1/2-INCH CHILL; NO. 3 AGAINST 3/8-INCH CHILL; NO. 4 AGAINST 1/4-INCH CHILL; NO. 5 AGAINST 3/16-INCH CHILL; NO. 6 AGAINST 1/8-INCH CHILL; NO. 7 AGAINST 1/16-INCH CHILL

cooling on his own product and to the approach of a solution to his chemical problems.

It is obvious that, regardless of the silicon content, the more near medium the pouring temperature, the closer will be the

grain in the iron where it is poured in contact with a chill; whereas in the sand cast blocks, the lower the temperature, the finer will be the grain of the iron.

These statements are borne out by the experiment shown in Fig. 2, which shows the fractures of iron cast on a chiller from the same ladle with the temperature varying. It is interesting to see the marked effect that temperature has on the depth of the chilled metal.

Influences on Chill

Before proceeding further, it might be well to show some of the other influences which affect the "chill" produced in cast

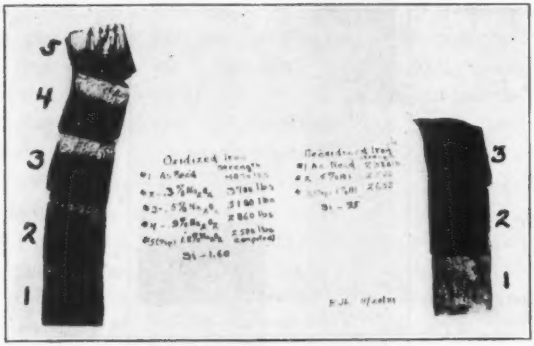


FIG. 4—EFFECT OF OXIDATION ON CHILL. OXIDIZED IRON SPECIMENS ON THE LEFT, DEOXIDIZED SPECIMENS ON THE RIGHT

iron by "chillers." Fig. 3 represents the effect of thickness of the chiller upon the chill produced. It will be noticed that where the 1/16-inch chiller and the sand cast blocks are compared that there is no appreciable difference. But those blocks cast on the chillers varying from 1/8 to 3/4-inch in thickness have an increasing amount of chill produced in their fracture.

Oxidation in iron produces chill as illustrated in Fig. 4, while de-oxidation with aluminum softens the chilled iron, as shown at the right of the same picture. The pouring temperature, size of chiller and all factors were held as constant as possible in order to prove that oxidation affected the depth of chill.

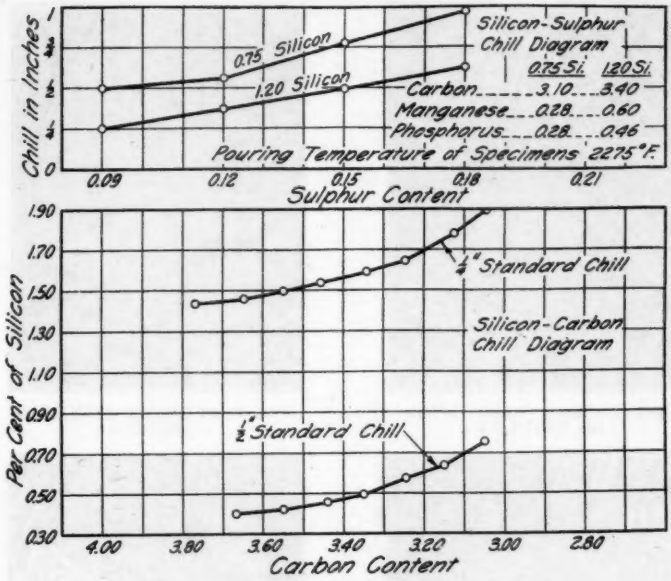


FIG. 5—SILICON-SULPHUR CHILL DIAGRAM

Fig. 5 shows the effect of the elements, sulphur, silicon and carbon on a chill. The graphs are self-explanatory, and, therefore, will not be interpreted.

There are influences exerted by alloys such as chromium, nickel, molybdenum, etc., which have been investigated but time and space will not permit their introduction in this paper. Let it suffice to say that they are beneficial to chill in varying degrees.

Another important factor which influences the production of chill metal is the melting medium used. If an iron is melted in a cupola, its microstructure is different from an air furnace melted iron. This difference will be shown in a later part of this paper. It is important, however, to bear in mind that the method of melting has a direct bearing upon the quality of the chill produced.

A Short Technical Discussion of Chill

When a metal comes into contact with a chilling surface, solidification sets in. The greater the ability of this chilling sur-

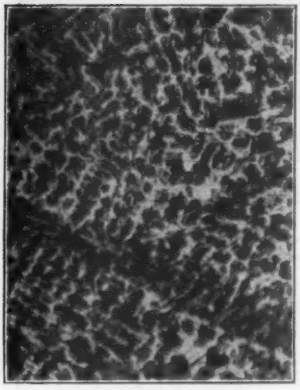


FIG. 6—SHOWING GROWTH OF DENDRITE

FIG. 7—SHOWING GREY IRON STRUCTURE

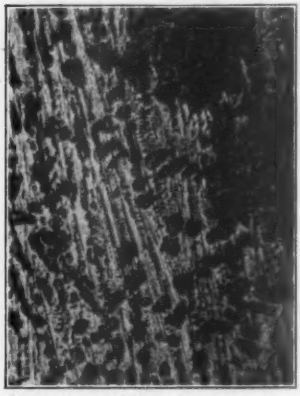


FIG. 8—SHOWING MOTTLED IRON

FIG. 9—SHOWING WHITE IRON

face to dissipate heat, the quicker the crystal formation starts. Where this crystallization is most rapid, in the case of a "chiller," it takes place markedly inward from the chilling surface. "Main trunks" are established, as shown in Fig. 6, which enrich with the impurities, the molten metal out of which they grow, due to these trunks being of a purer composition. This leaves this richer metal, to be formed by diffusion, to solidify later. By virtue of this metal surrounding the "main trunks" being made

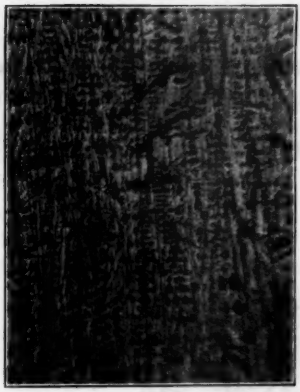


FIG. 10—WHITE IRON
100 X

FIG. 11—WHITE IRON—SAME AS NO. 10 — 250 X

FIG. 12—CHILLED ROLL NO. 1
SIZE 12½ x 30 INCHES
CUPOLA IRON

FIG. 13—CHILLED ROLL NO. 2
SIZE 36 x 84 INCHES—AIR
FURNACE IRON

richer, solidification begins to take place faster at right angles to the trunks. Consequently, "branches" are set up which make the crystals take the appearance of a "pine tree" or dendritic crystal.

This peculiar type of solidification is caused by the fact that the tips of branches extend freely into the liquid metal, between the "main trunks." This gives them the opportunity to

accumulate or grow from depositions out of the enriched surrounding metal, whereas the main stems become more or less locked up by the branches which extend from their bodies. This prevents their quick contact with the enriched mother metal to the impediment of their growth.

There are some of these dendritic crystals which stand in relief which are called "bas relief" dendrites. These are caused by the level of the still unfrozen metal being moved from its normal position by the contraction and expansion of the mold. These alterations in the mold affect the vertical and horizontal

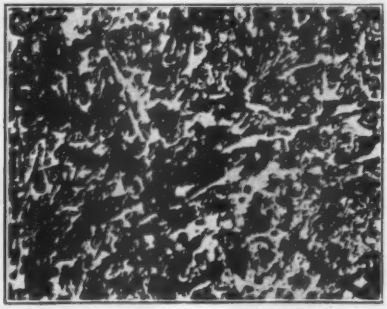


FIG. 14—CHILLED ROLL NO. 4—SIZE 24 x 48 INCHES—AIR FURNACE IRON

position of the freezing metal with a resulting raising of the relatively rigid solidifying dendrite out of its proper position. By reference to Fig. 15 such bas relief dendrites may be nicely seen. They are represented by the outstanding shining areas. Such a condition in the chilled mass sets up planes of weakness.

The difference in the chemistry of the iron, as cited previously, arises during the solidification of the molten metal which proceeds differentially by the deposition of solid layers increasing progressively in richness of the elements. This act is somewhat limited by the rate of cooling from all sides of the mold. In some instances, a wide difference in chemistry in the successive layers of the solidified mass is somewhat lessened due to the diffusion of the elements after solidification has been finished. This is exceedingly true of the element, carbon, which attempts to migrate in order to distribute itself homogeneously throughout iron.

In verification of the results of the experiment shown and the foregoing statements, one authority states, "In solidification of chilled metal, the concentration of the carbon, phosphorus and sulphur which occurs in the deposition of each successive layer would naturally push these segregating elements forward into the last freezing region, which is usually in the upper part of the axis and immediately below the pipe."

It has not been possible to show the difference in the chemistry of the successive depositions of the metal by microscopic effort. But the effect of dendritic solidification is shown by the microphotographs of Figs. 10 and 11. By referring to these, it may be seen how the enriched mother metal becomes land locked by the "stem" and branches of the "pine tree" crystal. It is interesting to note that the small black areas may be resolved, by etching reagents and by the use of sufficiently large diameters, to show that pearlite, cementite, iron and the regular impurities called "sonims," cover this body.

Sauveur and Krivobok in their latest work have nicely shown that the "fillings" between the stems or branches contain these inclusions as well as the general alloying elements. Their work was performed upon steels but their conclusions are analogous to cast irons.

For the layman's purpose, microphotographs of Figs. 7 to 9 inclusive are attached. These show the effect upon the structure of cast iron, which may be caused by varying the chemistry or cooling times of the mass. All of these structures appear in large chill casting such as chill rolls, i.e., the structure of Fig. 7 would be in the center; the structure of Fig. 8 would appear between the chilled iron and the structure of Fig. 7; while the structure of Fig. 9 would be found in the hard iron imposed by the chiller. The same holds true for chilled car wheels and in the case of "grey back" mold boards.

Practical Investigation—Chill Rolls

In order that the theoretical research might be of more than passing value, it was decided that an investigation of the effect of the deposition of the chemical elements would be examined in chilled rolls.

Five rolls were selected in two different foundries. The

turnings were taken from these rolls while they were in the lathes. The points from which the turnings were cut are shown by the markings of Fig. 15. These samples were taken from the end of the roll and therefore must not be considered representative of the roll. They were taken carefully and prepared for the analytical determinations with extreme precaution in order that we might see whether our theoretical work had practical value.

The results are shown in Table 2. It is interesting to notice the difference in the manufacturers' analyses and those of the successive layers. There is further an interesting fact

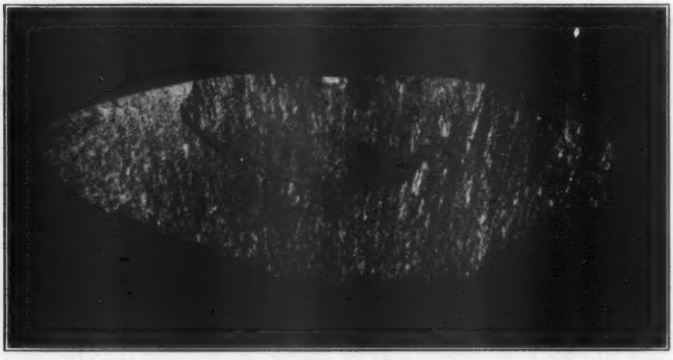


FIG. 15—SECTION OF CHILLED ROLL SHOWING SECTIONS A, B AND C, FROM WHICH TURNINGS WERE TAKEN

shown by comparing rolls 2, 3 and 5 to rolls 1 and 4. It is shown by these comparisons that the carbon segregation is lessened in the rolls by the use of a higher silicon. The manganese in these experiments remained fairly constant while the phosphorus was driven to center as was the case in the test block experiments. The sulphur carried the same tendency of relieving itself from the immediate area of the chiller and reverting towards the center of the roll.

Therefore, the effect of the deposition of the elements in a chill roll is somewhat in accordance with the theoretical conclusions drawn in the earlier part of this paper.

The effect of the melting medium on the structure is

Table 2

Specimen	ROLL DATA: Size in Inches	Weight	Method of Manufacture	ANALYSIS: Location of Analysis	Total Carbon	Silicon	Sulphur	Manganese	Phosphorus	Depth Chill, in Inches
No. 1	12½x30	1450	Cupola	Manfr. Analysis		.61	.136	.41	.340	3
Mixture:				Point A	3.02	.63	.111	.37	.310	
Car wheels	45 per cent			Point B	3.09	.59	.127	.42	.329	
Steel	25 per cent			Point C	3.21	.61	.136	.39	.347	
Bessemer iron.....	10 per cent									
Charcoal iron.....	20 per cent									
	100 per cent									
				Manfr. Analysis		.82	.071	.19	.474	1½
No. 2	36x84	35500	Air furnace	Point A	2.90	.87	.061	.16	.467	
Mixture:				Point B	2.99	.81	.065	.21	.470	
Scrap rolls.....	70 per cent			Point C	3.04	.83	.069	.19	.479	
Coke and charcoal ir.	30 per cent									
	100 per cent									
No. 3	12¾x30	1475	Cupola	Manfr. Analysis		.68	.154	.30	.286	1½
Mixture:				Point A	3.10	.74	.121	.29	.270	
Car wheels.....	45 per cent			Point B	3.17	.65	.138	.32	.279	
Steel	25 per cent			Point C	3.24	.69	.165	.30	.294	
Bessemer iron.....	10 per cent									
Charcoal iron.....	20 per cent									
	100 per cent									
				Manfr. Analysis		.47	.105	.18	.398	4½
No. 4	24x48	8700	Air furnace	Point A	2.78	.49	.068	.16	.354	
Mixture:				Point B	2.89	.42	.079	.19	.378	
Scrap rolls.....	70 per cent			Point C	2.99	.47	.109	.18	.394	
Coke and charcoal ir.	30 per cent									
	100 per cent									
				Point A	3.02	.78	.099	.29	.393	2¾
No. 5	36x84	35550	Air furnace	Point B	3.04	.71	.102	.30	.395	
				Point C	3.13	.75	.109	.29	.402	

Table 3

CAR WHEEL IRON

Segregation Tests* Untreated Metal

Sample No.	Location of Sample	Analysis Number	Silicon, Per Cent	Manganese, Per Cent	Phosphorus, Per Cent	Sulphur, Per Cent
1	½ inch back of chill, 1 inch from cope	4659	.68	.58	.316	.216
2	½ inch back of chill, 2 inches from cope	4658	.68	.56	.296	.212
3	½ inch back of chill, 3 inches from cope	4657	.69	.59	.316	.214
4	½ inch back of chill, 4 inches from cope	4656	.69	.58	.298	.214
5	½ inch back of chill, 5 inches from cope	4655	.69	.58	.304	.208
6	½ inch back of chill, 6 inches from cope	4654	.69	.58	.304	.206
7	½ inch back of chill, 7 inches from cope	4653	.66	.58	.296	.218
8	½ inch back of chill, 8 inches from cope	4652	.67	.58	.292	.214
9	1½ inches back of chill, 1 inch from cope	4651	.67	.58	.285	.218
10	1½ inches back of chill, 2 inches from cope	4650	.66	.60	.292	.218
11	1½ inches back of chill, 3 inches from cope	4649	.65	.58	.298	.216
12	1½ inches back of chill, 4 inches from cope	4648	.65	.59	.295	.216
13	1½ inches back of chill, 5 inches from cope	4647	.66	.57	.292	.216
14	1½ inches back of chill, 6 inches from cope	4646	.65	.58	.304	.214
15	2½ inches back of chill, 1 inch from cope	4645	.65	.60	.296	.222
16	2½ inches back of chill, 2 inches from cope	4644	.66	.60	.299	.210
17	2½ inches back of chill, 3 inches from cope	4643	.66	.59	.294	.222
18	2½ inches back of chill, 4 inches from cope	4642	.66	.60	.298	.222
19	2½ inches back of chill, 5 inches from cope	4641	.65	.58	.298	.212
20	3½ inches back of chill, 1 inch from cope	4640	.66	.60	.292	.226
21	3½ inches back of chill, 2 inches from cope	4639	.67	.61	.292	.217
22	3½ inches back of chill, 3 inches from cope	4638	.66	.58	.295	.202
23	4½ inches back of chill, 1 inch from cope	4637	.61	.60	.298	.200
	Treated Metal					
1	½ inch back of chill, 1 inch from cope	4670	.66	.55	.346	.154
2	½ inch back of chill, 2 inches from cope	4671	.67	.55	.325	.156
3	½ inch back of chill, 3 inches from cope	4672	.67	.55	.306	.156
4	½ inch back of chill, 4 inches from cope	4673	.69	.54	.316	.152
5	½ inch back of chill, 5 inches from cope	4674	.69	.55	.322	.150
6	½ inch back of chill, 6 inches from cope	4675	.69	.55	.328	.156
7	½ inch back of chill, 7 inches from cope	4676	.67	.56	.316	.156
8	½ inch back of chill, 8 inches from cope	4677	.67	.55	.322	.148
9	1½ inches back of chill, 1 inch from cope	4678	.66	.55	.304	.158
10	1½ inches back of chill, 2 inches from cope	4679	.65	.55	.306	.150
11	1½ inches back of chill, 3 inches from cope	4680	.66	.55	.304	.152
12	1½ inches back of chill, 4 inches from cope	4681	.66	.58	.292	.154
13	1½ inches back of chill, 5 inches from cope	4682	.65	.57	.304	.154
14	1½ inches back of chill, 6 inches from cope	4683	.66	.57	.298	.156
15	2½ inches back of chill, 1 inch from cope	4684	.65	.58	.304	.156
16	2½ inches back of chill, 2 inches from cope	4685	.67	.57	.310	.160
17	2½ inches back of chill, 3 inches from cope	4686	.68	.57	.320	.150
18	2½ inches back of chill, 4 inches from cope	4687	.68	.58	.320	.154
19	2½ inches back of chill, 5 inches from cope	4688	.68	.55	.300	.156
20	3½ inches back of chill, 1 inch from cope	4689	.67	.57	.292	.164
21	3½ inches back of chill, 2 inches from cope	4690	.66	.59	.299	.153
22	3½ inches back of chill, 3 inches from cope	4691	.66	.57	.318	.156
23	4½ inches back of chill, 1 inch from cope	4692	.64	.58	.296	.162

*Griffin Wheel Company.

self-evidenced by the microphotographs of Figs. 12 to 14 inclusive. The specimens for these pictures were taken from the same relative positions from rolls of cupola and air furnace manufacture. The effect upon the structures of the resulting metal from these two processes is obvious. The char-

acteristics of these structures are influenced, of course, by the diameter and size of the rolls and their respective analyses. But, from previous work on chill metals taken under like conditions of size, analysis, etc., there is a marked divergence in the structures of the cupola and air furnace product. It is assumed from experience that the air furnace produces the superior product for certain quality of work to be imposed on a casting.

Investigation of Chill Car Wheels

In order to make this investigation more complete, a series of tests were run on chill car wheels. The results in

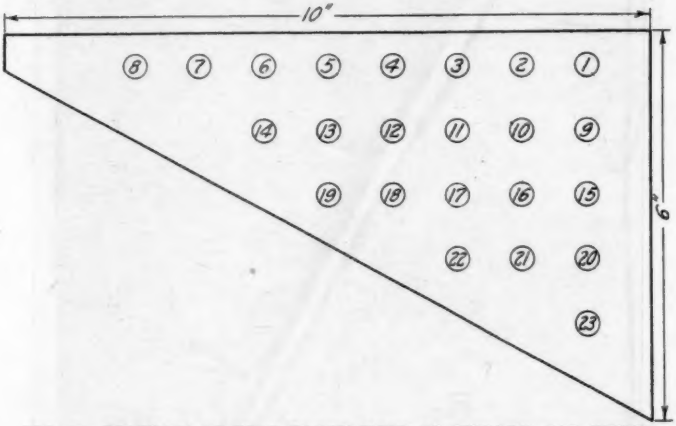


FIG. 16—DIAGRAM OF TEST BLOCK USED IN CHILLED CAR WHEEL EXPERIMENTS

this case were not so satisfactory inasmuch as the difference in the analyses of the successive layers of solidification did not show such a marked segregation of chemical elements. There was an appreciable variation, however, in the deposition of the elements.

It was thought best to work out our problem on a triangular test block, such as shown in Fig. 16. The analyses of these two blocks are given in Table 3. The structure prints are illustrated in Fig. 17. These are reduced in reproduction from the size indicated in Fig. 16.

FIG. 17—UNTREATED TEST BLOCK CAR WHEEL IRON, FIG. A. TREATED TEST BLOCK CAR WHEEL IRON, FIG. B

The results shown do not bear out those of the other investigation. Inasmuch as the only factor which differs mightily in this experiment and the others is sulphur, it is felt that this element is in preponderance in a way which prevents the normal expectancy from happening. In other words, sulphur upsets the equilibrium of solidification perhaps to retain or reject the elements in their reverse order. It is only fair to assume this because of the vast amount of work performed on low sulphur irons and their concurrence in checking.

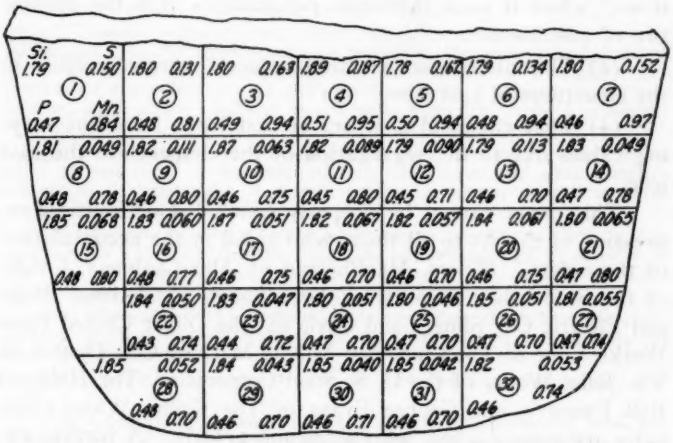


FIG. 18—DIAGRAM OF SECTION OF CAST IRON METAL FROZEN IN LADLE. ANALYSIS SHOWS SEGREGATION

It may be of interest to compare the treated and untreated phases of these two test blocks. The treated block was poured from the same iron as the untreated block. A desulphurizing compound was used in reducing the sulphur, as shown in the analyses.

The Grey Iron Investigation

To conclude the investigation, the following experiment on a section of metal which was cut from a block of metal frozen in the ladle is offered. The analyses are shown in Fig. 18, which is a diagram of the section of this block of metal.

The results are obvious. The segregation was one of normal expectancy and tends to prove that in solidifying, a metal tries to reject its impurities.

Conclusions

It may be concluded—(1) that in ordinary chill irons, the chiller rejects the chemical elements from the chilled surface of any iron poured in contact with it.

(2) That sulphur upsets the normal "solidifying rejections," when it is in increased percentages over the regular run of cast irons.

(3) That air furnace metals produce superior qualities in the structures of cast iron.

(4) That chemical analyses of cast irons have but varying values due to the segregation of the elements in the cast iron.

This paper cannot be properly concluded without an expression of thanks to all those who aided in the accumulation of these data. Messrs. MacPherran of Allis-Chalmers, Crosby of the Studebaker Corporation, Greenhough of National Brake and Electric Co., Slinger and Coyle of The Oliver Chilled Plow Works, Cone of The Cincinnati Milling Machine Co., Thomas of The Joliet Works of the U. S. Steel Corporation, The Hubbard Roll Foundry, and George Evans of The Griffin Wheel Company are among a few who aided me greatly. A further expression of thanks must be given to the Oliver Chilled Plow Works and Hickman, Williams & Company for their extending the writer the privilege of conducting these experiments while in their respective employ.

Nomenclature

(1) *Cast Iron:*—A compound of iron, carbon and other elements, where the percentage of iron is over 95.00 per cent and the carbon above 2.25 per cent. Because of the high percentage of carbon, the material is not generally malleable.

(2) *Chill Iron:*—A compound of the same description as cast iron, but whose combined carbon is higher than regular iron or whose fracture is white. It is a hard iron.

(3) *Grey Iron:*—A compound of the same description as cast iron, but whose fracture is grey, due to the presence of great percentages of graphite. This is the soft grade of cast iron.

(4) *Mottled Iron:*—A cast iron between the grades of chill and grey, whose fracture is mottled with white spots in which there is no graphite and with grey portions where graphite is seen.

(5) *Carbon:*—An element which exists in at least two states in cast iron, i. e., graphitic and combined.

Graphitic Carbon:—The carbon which is free from combination with any other element in cast iron. It is the softening element of cast iron.

Combined Carbon:—The carbon which is in combination with the iron in the form of carbides or cementite (Fe_3C—3 parts of iron plus one part of carbon). It is a hardening element in cast iron.

(6) *Silicon:*—An element which associates itself with the iron to unstabilize the iron-carbon compound, thus forming graphite and softening the cast iron. Its formation in the latter is called a silicide (iron plus silicon) which in excess proves to be a hardener of iron.

(7) *Sulphur:*—An element which associates itself with iron or with manganese. In the former case it stabilizes the carbon and hardens the iron. In the latter case it becomes insoluble in the iron and either frees itself from the latter by entering the slag or it remains in the iron to form hard spots. Sulphur is generally conceded to be a weakener of iron.

(8) *Phosphorus:*—An element which tends to lower the freezing point of cast iron. It has relatively no effect upon the other elements present in this material. It forms several compounds with iron which are generally said to be weakeners.

(9) *Manganese:*—An element which serves several functions in cast iron, i.e., as (1) a de-oxidizer, (2) a de-sulphurizer, (3) to dissolve in the iron and strengthen it in some percentages, (4) to form carbides which appear as grey spots in irons of white fracture.

(10) *Chromium:*—An element, more rare than those heretofore described, which is used to stabilize the combined carbon and increase the hardness of cast iron.

(11) *Ferrite:*—An element—iron—a soft, ductile, easily welded material.

(12) *Cementite:*—A hard, brittle, glass-like compound of iron and carbon (Fe_3C). It is iron with 6.67 cent carbon associated or for each one part of carbon there are fourteen parts of iron. It is one of the chief constituents of white iron. It is found dissolved and undissolved in iron.

(13) *Austenite:*—The non-magnetic state of iron. It is similar to high temperature non-magnetic ferrite, differing from it only in containing varying percentages of carbon in solution. This carbon is undoubtedly in the form of cementite, dissolved and undissolved in the iron. Therefore, the composite of cast iron is represented by the total amount of austenite with the following exceptions:—The austenite does not include all of the undissolved cementite. Therefore, allowance must be made for it.

Austenite is, therefore, solid iron with carbon, probably in the form of cementite in varying proportions, dissolved in it. In the ordinary carbon-iron series austenite exists alone at high temperatures which destroy the structural forms such as pearlite, sorbite, etc.

(14) *Pearlite:*—A structure, in iron and steel, which has the appearance of a mother of pearl or the stripes of a zebra. This appearance is caused by the interstratification of cementite with 6.4 times its own weight of ferrite. Pearlite usually contains 0.90 per cent carbon.

(15) *Eutectic:*—A solution with the lowest freezing point. As an example: Iron with no carbon freezes at 1530 degrees Cent. (2786 degrees Fahr.), but this temperature is continually lowered with additions of carbon until 1135 dgerees Cent. (2069 degrees Fahr.) has been reached at 4.30 per cent carbon. With further additions of this element the temperature is raised until 2000 degrees Cent. (3032 degrees Fahr.) has been reached with 6.7 per cent carbon. Therefore, 4.30 per cent carbon is the eutectic or the alloy of iron carbon with the lowest freezing temperature.

(16) *Dendrite:*—A tree-like aggregation of a great number of very minute crystals, whose axes have the same direction. This formation differs from the average crystal forms only in its general outer structure which is composed of a "trunk" and "branches," often somewhat curved. A "Dendrite" has the similar appearance of the frost formations on a window pane.

(17) *Austenoid:*—A special complex structural formation of iron-carbon of which 86 per cent is pearlite and 14 per cent is structure free cementite. An iron containing 1.70 per cent total carbon would be composed of 100 per cent of this structure. In white cast irons, this structure appears in black areas between the white comb formation of the eutectic cementite. "Hypo" and "Hyper" may be prefixed to austenoid to denote a composition of less than or greater than 1.70 per cent carbon.

(18) *Primaustenoid:*—All the austenoid which is not included as a part of the eutectic.

The Electric Furnace in the Pipe Foundry

By James T. MacKenzie, Birmingham, Ala.

The situation in the cast iron pipe industry at the beginning of 1919 was very uncertain. The government had suddenly withdrawn from the market and other consumers were loath to buy at the prices obtaining at the time. In considering the situation it seemed necessary to reduce the cost to the consumer and this could be best accomplished by reducing the metal thickness of the pipe which called for an equivalent increase in the strength of the metal. The saving which could be effected was not only the actual cost of the metal in the foundry but the considerable reduction in freight which was in many cases one-third of the cost to the consumer.

Scrap Metal Used to Increase Strength

To accomplish the increase in strength of metal it was necessary to increase the percentage of scrap in the mixture, especially steel scrap which had the additional advantage of some $10.00 per ton in price and was available in large quantities. Other scrap such as car wheels, stove plate, etc., was also available if means could be found to employ it satisfactorily. The electric furnace had come prominently to the front as a means of converting low grade materials into a satisfactory product and it was decided to install one. This seemed to offer a solution to the problem of using direct blast furnace metal which had previously been tried and abandoned on account of the difficulty of keeping it hot enough for the work. A mixture of cupola melted scrap with direct metal was especially attractive as there would be no deterioration of that portion of the mixture used direct and no melting cost to add to the price. The electric furnace offered itself as a de-oxidizer for the cupola metal and as an effective superheater for the direct metal or the mixture of the two.

The American Cast Iron Pipe Company installed a six ton

Ludlum furnace and began operations with it on June 1st, 1919, running on an acid bottom. For the first month the operation was simple superheating of cupola iron carrying high percentages of scrap including some 15 per cent to 30 per cent steel. This was held for ten or fifteen minutes in the furnace under a cover of cupola slag and a little coke breeze, which was usually long enough to give the slag a dark green color and the metal a temperature rather higher than was necessary. This operation was quite satisfactory, giving an iron of fairly good casting properties and high strength, the standard 2 x 1 x 26 inch bar averaging about 2,600 pounds with a deflection of about 0.40 inch.

Direct Metal Tried Out

Direct metal from a nearby furnace was introduced on July 1st using small hemispherical pots of 15 to 20 ton capacity. It can readily be seen that this metal of approximately 3.0 per cent silicon, 0.03 per cent sulfur, and 0.5 to 1.0 per cent manganese used without the losses sustained in passing through the cupola (which are higher when much steel is used) would allow the use of very high percentages of scrap in the cupola when used in the proportion of two parts direct to three parts cupola iron. The mixture was given about twenty minutes treatment, which was ample for deoxidation and superheating.

This operation was continued until June, 1920. There were several conditions acting against its continuance. The care and upkeep of the pots was more expensive than had been anticipated. Stock conditions at the blast furnace were not good and the metal was varying too much from cast to cast. Stocks at the local scrap yards were inadequate to enable us to keep the correct proportion of cupola metal to direct metal. We were being forced to an excess of steel scrap in order to get low silicon cupola metal where we had been able to get low silicon cast scrap sufficient for the purpose when we started. This lowered the carbon too much, especially on the high silicon pots where the carbon was already low in the direct metal. The slightest mishap in cupola operation on these high steel mixtures further aggravated the condition.

Segregation of Manganese Sulphide Causes Trouble

The furnace was then put on a normal grey iron mixture running about 1.8 per cent Si, 0.08 per cent S, 0.4 per cent Mn, 0.7 per cent P, and 3.5 per cent C. Cold steel was added to the cupola metal in the furnace sufficient to reduce the carbon about 0.2 per cent. This took a little more time but was much more satisfactory and easy to work. There was quite a bit of trouble from the high freezing point of this iron. We had to pour it at one or two hundred degrees Fahr. above that of the normal cupola iron and if we got it too hot we had trouble with cutting of the molds and cores and with segregation of manganese-sulphide in the top of the casting. We tried adding ferro-phosphorus to restore the fluidity, but with no appreciable results. We also tried raising the manganese but the segregation increased.

To overcome this we changed to basic bottom in December, 1920, resuming operations about January 1st, 1921. The furnace was given the iron from only one cupola which was run on a high scrap mix of approximately 1.3 per cent Si, 0.10 per cent S, 0.3 per cent Mn, 0.6 per cent P., and 3.2 per cent C., in the ladle. One ladle, 3½ tons, of cupola iron was charged, the current turned on, and slag materials added. By the time the next ladle was ready to go in, the slag was fluid and sulfur reduction had begun. The current was not interrupted for the addition of the second ladle so by the time the third ladle from the cupola was ready the furnace was ready to tap, alloy additions having been made some three to five minutes previously. Sulfur reductions averaged about 0.04 per cent—bringing the metal down to about 0.06 per cent.

Re-Carburization Tried to Increase Pouring Range

The pouring range was still too narrow, in fact the sulfur reduction did not seem to help much so we tried re-carburizing, first in the furnace with coke breeze and green poles, and then with blacking in the ladle. Poling was very unreliable and quite expensive but the blacking gave a very nice recovery of some 0.2 per cent carbon from 0.5 per cent charged. This widened the pouring range somewhat, but it was still too high, so after

trying silicons up to 2.5 per cent, sulfurs down to 0.03 per cent, and manganese all the way from 0.3 per cent to 1.2 per cent without material relief, we abandoned the scrap mixture altogether and tried simple deoxidizing and desulfurizing of the regular mix. The pouring temperature was still very distinctly higher after treatment than before though it was entirely possible to make remarkably tough metal with this simple treatment, four inch standard class "B" pipe being almost unbreakable with an eight pound hammer and the test bar giving nearly 3,000 pounds transverse strength with a deflection of nearly 0.5 inch. This operation could undoubtedly have been worked out very satisfactorily but by this time, March, 1921, the price of pig had gone down so much more than scrap that the differential was not enough to cover the cost of operating the furnace, so after due consideration the furnace was shut down on April 1st, 1921.

Electric Furnace Grey Iron

By Edwin L. Willson, Philadelphia, Pa.

Numerous papers have been presented before this and other similar associations during the past few years, describing experimental and research work which has been conducted on the carburization of steel to produce grey and white cast iron. The majority of these papers have described experiments which were conducted on a relatively small scale, and, while they have demonstrated the practicability from a metallurgical standpoint of the process of producing so-called synthetic iron in the electric furnace, the scope of the experiments was hardly sufficient to obtain accurate average data regarding the costs of the process. The economical considerations are of considerable interest to central station companies who are in position to furnish the large amount of electric power necessary to the process. In the fall of 1922 the unusually large differential in price between pig iron and steel scrap at New England points presented an opportunity for making an experimental run of synthetic gray iron, and disposing of the product at a price sufficient to pay the cost of the test. The Hartford Electric Light company was interested in obtaining cost and metallurgical data on the process, and as the plant of the Connecticut Electric Steel company, containing two 2-ton Heroult steel furnaces, was available, the experiment was begun on November 16, 1922, under the supervision of the writer.

The primary object was to determine the commercial possibilities for a central station to produce synthetic pig iron from steel scrap utilizing off-peak power at a price to compete with the blast furnace product used by iron foundries. Coincident with this, it was desired to determine the relative cost and metallurgical characteristics of synthetic grey iron made direct into castings as compared with those produced in iron foundries by the cupola process. At the same time it was hoped to obtain metallurgical data concerning the process itself covering a

variety of compositions of iron within a range possible of disposition of the product.

Several iron foundries in the neighborhood of Hartford agreed to co-operate to the extent of purchasing the pig iron produced if it could be made to meet their standard specifications, and also to furnish molds for the production of castings.

Economic Factors

The economic factors which govern the possibilities of synthetic iron are the relative costs of pig iron delivered in a given district and the net value of steel and iron scrap produced in

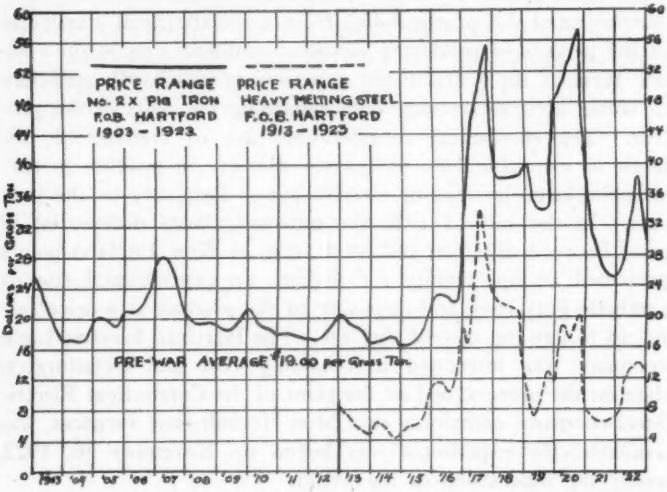

PRICE RANGE
No. 2X PIG IRON
F.O.B. HARTFORD
1903 - 1923.
PRICE RANGE
HEAVY MELTING STEEL
F.O.B. HARTFORD
1913 - 1923
PRE-WAR AVERAGE $19.00 per Gross Ton.
Dollars per Gross Ton
'03 '04 '05 '06 '07 '08 '09 '10 '11 '12 '13 '14 '15 '16 '17 '18 '19 '20 '21 '22

FIG. 1—CHART SHOWING COMPARISON OF PRICE OF PIG IRON AND HEAVY MELTING STEEL FOR YEARS OF 1913 TO 1923

that district—in other words, localities sufficiently removed from the large steel and iron districts for the freight cost to be considerable on pig iron purchased from and scrap sold for shipment to the steel centers. The price differential between No. 2X foundry pig iron and steel scrap at Hartford is shown graphically in the accompanying charts of Figs. 1 and 2.

The Term "Synthetic Iron" Misleading

The term "synthetic iron" has been applied to grey iron which is produced by raising the carbon content of steel by the addition of a carbonizing agent, such as coke or charcoal, to a point approximating 3½ to 4 per cent, which is the average carbon content of blast-furnace iron. The term has been extensively used in articles on this subject, but is slightly mis-

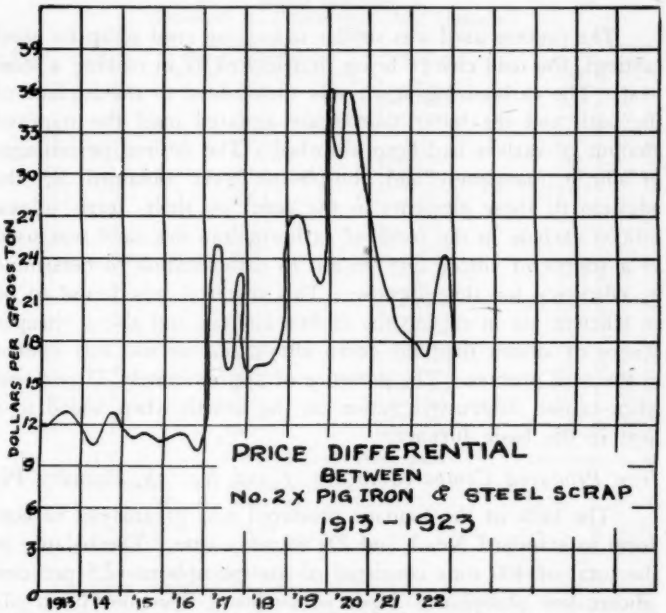


FIG. 2—PRICE DIFFERENTIAL BETWEEN NO. 2X PIG IRON AND STEEL SCRAP, 1913 TO 1923

leading, as it implies the use of chemical reactions to produce a complex chemical compound from elementary substances. The term is applicable as regards the elements iron and carbon, while the metal is in the molten condition, but the analogy is less apparent after solidification, when grey iron becomes in reality an admixture of an alloy steel with graphite. The raw material used in these experiments was principally basic open-hearth

steel scrap of about 0.20 per cent carbon. Large tonnages of this material are available in New England as a by-product from the many industries in which duplicate parts are produced by stamping from cold-rolled strip steel.

The direct melting of grey iron in the form of pig, scrap or borings was not attempted, as this process did not offer any economic possibilities in this territory.

Process Used

The process used was similar to melting steel scrap for steel castings, the cold charge being first melted as in making a steel heat. The carbonizing agent was then added to the surface of the bath and the latter thoroughly agitated until the required amount of carbon had been absorbed. The desired percentages of silicon, manganese and phosphorus were obtained by the addition of these elements in the form of their ferro alloys. Silicon carbide in the form of carborundum fire sand was used as a source of silicon and an aid to carburization to determine its efficiency for this purpose. This material was found to be an efficient aid in raising the carbon content and also a cheaper source of silicon than the ferro alloys, but its use was limited to the acid process. The presence of approximately 25 per cent silica caused destructive action on the hearth when added to a heat in the basic furnace.

Iron Produced Compared to No. 1 and No. 2X Foundry Pig

The bulk of the tonnage produced was of analysis to conform to standard No. 1 and 2X foundry iron. The balance of the total of 400 tons consisted of low phosphorus 2.5 per cent silicon, low phosphorus 2 per cent silicon, Bessemer ferro silicon and iron with a specified content of chromium and nickel. One very considerable item of cost was the necessity of adding phosphorus in the form of ferro phosphorus in order to raise the percentage of this element to approximately 0.70 per cent in order that the pig iron would be suitable for foundry use in a cupola. The low phosphorus iron was taken in by the foundries and used in their mixtures in place of charcoal iron. The castings made direct from the electric furnace were all poured from heats low in phosphorus.

The melters in charge of the furnace were experienced in the melting and refining of carbon and alloy steel, but had no previous experience in the production of grey iron from steel scrap. After the first few heats where fracture tests were checked by chemical analyses, they were able to judge the rise of carbon content accurately and could finish heats with per-

Table 1

Summary of Production, Acid Process

Date	Heats Made	Weight of Charge—Pounds	Grades	Power Consumed by Furnace
Nov. 6	0	(Burning in Acid Bottom)		2380 K. W. H.
6	1	3928	Low Phos.	1130 K. W. H.
7	3	12219	Low Phos.	4159 K. W. H.
8	2	8610	Low Phos.	3061 K. W. H.
9	6	24750	2-X	6480 K. W. H.
10	7	28916	2-X	8450 K. W. H.
11	4	15977	Low Phos.	5480 K. W. H.
13	14	59964	Low Phos.	16800 K. W. H.
14	11	48785	L. P. & No. 1	13890 K. W. H.
15	3	13295	Low Phos.	4155 K. W. H.
16	0	(Burning in Bottom)		2220 K. W. H.
16	4	20960	No. 1 Fdy.	5392 K. W. H.
17	9	49385	No. 1 Fdy.	13033 K. W. H.
18	4	21671	No. 1 Fdy.	6324 K. W. H.
20	3	13155	Low Phos.	3654 K. W. H.
21	6	26160	Low Phos.	7313 K. W. H.
22	5	22275	Low Phos.	6285 K. W. H.
23	4	19210	Low Phos.	5260 K. W. H.
24	5	23002	Low Phos.	6132 K. W. H.
25	2	9204	Low Phos.	2478 K. W. H.
27	2	9146	Low Phos.	3040 K. W. H.
28	4	18342	Low Phos.	5510 F. W. H.
29	5	23030	Low Phos.	6555 K. W. H.
30	2	9156	Low Phos.	2435 K. W. H.
1	2	9156	Low Phos.	2680 K. W. H.
2	3	15150	Low Phos.	4090 K. W. H.
Total.....111		505446=225.646	Gross Tons	148386 K. W. H.

Add power used for other purposes (cranes, air compressor, etc.).....	12,796	K. W. H.
Total Power Consumed.....	161,182	K. W. H.
Deduct Power not used for melting.....	17,396	K. W. H.
Power used for melting only.....	143,786	K. W. H.
Power consumed per Gross Ton Charged.....	714.3	K. W. H.
Power consumed per Gross Ton Charged (Melting only)	637.4	K. W. H.

centages of carbon, silicon, manganese and phosphorus very close to the specification limits.

Acid Lined Furnace Used at First

The test was started with the furnace lined with acid refractories, and a total of 111 heats was made by the acid process, 505,446 pounds of material being charged with a power consumption of 148,386 kilowatt-hours, which includes energy

necessary to burn in the bottom; a summary of the production by the acid process is given in Table No. 1.

The acid process is a simple melting operation, as the silica slag does not permit of refining reactions to reduce the impurities, the resultant percentages of such impurities being the accumulated amounts present in the material charged. The

Table 2

Record of Chemical Analysis, Acid Process

Heat No.	Total Carbon	Si.	Man.	P.	S.
1	2.27	2.67	0.77	0.03	0.048
2	2.122	....	....	....	.....
3	3.04	2.55	1.04	....	.....
4	3.438	3.05	....	....	.....
5	3.252	3.39	0.99	0.056	0.056
6	3.434	2.43	1.00	0.035	0.067
7	.....	3.02	....	0.475	0.074
8	.....	1.74	0.93	.....	0.056
9	2.976	2.02	1.02	0.596	.....
12	2.584	2.44	1.16	0.673	0.045
13	2.824	3.30	....	.....	0.045
17	2.366	....	1.15	.....	.....
18	3.142	....	....	.....	.....
19	3.212	....	....	.....	0.048
20	3.320	2.57	1.05	.....	.....
23	3.266	2.78	....	.....	.....
28	2.460	2.23	....	.....	0.065
43	3.182	1.57	....	.....	.....
44	3.092	2.46	....	.....	.....
52	2.688	2.44	0.74	0.375	0.058
59	.....	3.10	0.97	.....	0.067
66	2.388	2.46	0.81	0.578	0.080
70	2.85	1.55	0.99	0.042	0.071
76	Transverse test bar broke at 6,200 lb.				
80	3.650	2.08	....	.....	.....
82	3.180	2.05	....	.....	.....
83	3.44	2.23	0.80	0.064	0.062
87	.....	2.27	0.88	.....	0.056
94	2.444	2.04	....	.....	0.044
99	3.026	2.92	....	.....	0.021
102	3.214	2.55	0.84	.....	0.054
105	3.536	2.32	....	.....	.....

analysis taken of typical heats of the various grades of iron produced is given in Table No. 2.

Low Sulphur Content Possible with Acid Furnace

The highest sulphur content noted was 0.08 per cent on heat No. 66 in which the carburizer used was gas works coke. Sulphur contents of 0.04 to 0.05 per cent were obtained regularly on heats carburized with petroleum coke or a mixture of high

sulphur coke and carborundum fire sand. The lowest sulphur content reported was 0.021 per cent on heat No. 99. This heat was carburized with charcoal, and, while the time and power consumed are greater than when coke is used, it was shown that extremely low sulphur iron may be made on an acid hearth by proper selection of raw materials.

The experience gained by this run of the acid process leads to the following conclusions:

1. If scrap of high quality as regards analysis is available, together with low sulphur coke, grey iron of excellent quality may be produced by the acid process.

2. If the iron is to be poured direct into castings, it may be produced on an acid hearth with medium sulphur coke, and the sulphur content of the resulting castings will be lower than the average run of cupola iron.

3. The acid process is not sufficiently flexible for the production of synthetic iron in the form of pigs for remelting in the cupola on account of the danger of running too high in sulphur.

4. The control of carbon, silicon, and manganese can be held within close limits, and iron with practically any percentage of these elements may be made at will.

5. For the production of foundry iron for remelting in the cupola, requiring phosphorus content of 0.40 per cent or higher for fluidity, the cost of adding ferro-phosphorus is too high to make the addition commercially practicable.

6. It was demonstrated that very small intricate castings of thin section could be poured from the electric furnace with synthetic iron in which the phosphorus content did not exceed 0.03 per cent. These castings were free from chill effect, and their machining qualities in all respects were equal to cupola castings. The very much lower phosphorus content resulted in increased strength and resistance to shock as compared with cupola melted iron.

Fluidity Possible with Low Phosphorus Metal

Fig. 3 shows castings of very thin section which were poured from low phosphorus iron, the necessary fluidity being obtained by super-heating the iron in the furnace before tap-

ping. Experienced cupola operators who observed the extremely hot iron at the spout predicted burnt iron, but no such effect was present in the castings. The lock case casting shown at the right is a piece which must stand rapid machining on a piece-work production basis. The castings from electric furnace iron passed through the regular machine processes without any difference being noted by the operators, so that con-

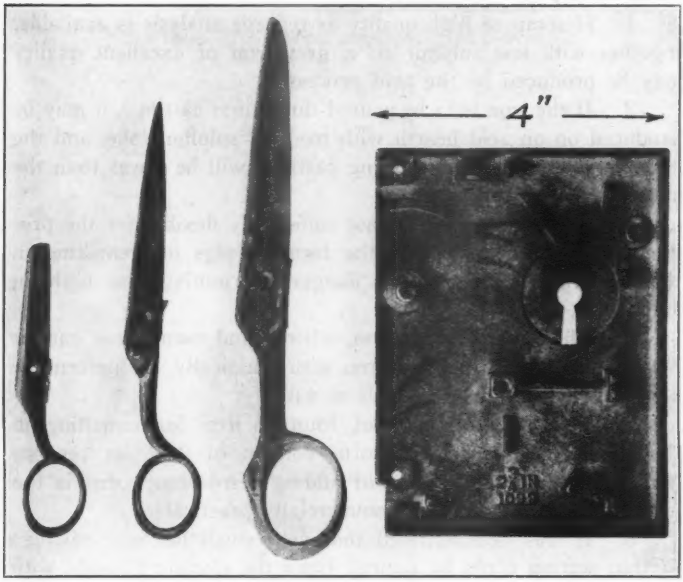


FIG. 3—CASTINGS OF VERY THIN SECTION POURED FROM LOW PHOSPHOROUS ELECTRIC FURNACE IRON

trary to some opinions there was no appreciable chill effect due to the higher pouring temperature. The production of these castings from cupola iron requires a high pig iron charge, principally No. 1 iron and the high phosphorus content necessary for fluidity results in castings having only about 50 per cent of the transverse strength which is shown by electric furnace iron. This extra strength has no practical bearing on this particular casting, but is cited to show the possibilities of increased strength

Table 3

Summary of Production, Basic Process

Date	Made	Weight of Charge (Burning in Basic Bottom)	Grades	Power Consumed
Dec. 2	0			6280 K. W. H.
4	1	4675	Mayari	1220 K. W. H.
5	4	18328	M. & No. 1Fdy.	5625 K. W. H.
6	5	23097	M. & No. 1 Fdy.	6115 K. W. H.
7	5	22865	L. P. & No. 1 Fdy.	6590 K. W. H.
8	4	18529	M. & No. 1 Fdy.	5130 K. W. H.
9	1	4725	Mayari	1210 K. W. H.
10	1	4725	Mayari	1690 K. W. H.
11	4	18900	Mayari	5110 K. W. H.
12	5	23623	Mayari	6480 K. W. H.
14	0	(Burning in Bottom)		6480 K. W. H.
14	1	4308	Low Phos.	1590 K. W. H.
15	2	10066	No. 2-X	2205 K. W. H.
16	2	8996	No. 2-X	2105 K. W. H.
18	3	13821	2-X & Cr. Ni.	3440 K. W. H.
19	6	27830	Cr. Ni. & Bess. Ferro Sil.	6620 K. W. H.
20	1	4725	Chrome Ni.	950 K. W. H.
Total.....45		209213=93.398 Gross Tons		68840 K. W. H.

Add power used for other purposes (cranes, air compressor, etc.)	3,978	K. W. H.
Total Power Consumed	72,818	K. W. H.
Deduct Power not used for melting	16,738	K. W. H.
Power used for melting only	56,080	K. W. H.
Power consumed per Gross Ton Charged	780	K. W. H.
Power consumed per Gross Ton Charged (Melting only)	600.4	K. W. H.

Total Production, Acid and Basic

156 Heats. 319.044 G. T. charged. Furnace Power	217,226	K. W. H.
Add power used for other purposes (cranes, air compressor, etc.)	16,774	K. W. H.
Total Power	234,000	K. W. H.
Deduct Power not used for melting	34,134	K. W. H.
Power used for melting only	199,866	K. W. H.
Power consumed per Gross Ton Charged	734	K. W. H.
Power consumed per Gross Ton Charged (Melting only)	627	K. W. H.

The total melting time (i. e. from time current was first thrown on furnace until heat was ready to pour) was 253 hours 39 minutes for 156 heats, or an average of 1 hour 37.6 minutes per heat, and 48 minutes per Gross Ton charged.

Table 4

Record of Chemical Analysis, Basic Process

Heat No.	Total Carbon	Si.	Man.	P.	S.
113	3.172	1.24	0.77	0.050	0.021
115	.....	3.15	0.77	0.68	*0.035
123	3.368	2.67	0.74	0.611	0.017
124	.....	3.44	0.70	0.038	*0.042
125	3.284	3.49	0.69	0.060	0.011
137	.....	1.03	....	.....	0.019
145	2.868	2.67	0.77	0.578	0.025
149-152	.....	1.82	0.83	0.043	0.041
154	1.768	11.23	0.71	0.029	0.014

*Sulphur determined by evolution. A check on heat 124 by the gravimetric method showed sulphur 0.011.

in thin section castings by the use of low phosphorus iron obtainable only from the electric furnace.

Basic Lining Used to Determine Refining Reactions

In order to determine the possibilities of refining reactions, the furnace was relined with a basic hearth and forty-five heats were made by the basic process, 209,213 pounds of material being charged with a power consumption of 68,840 kilowatt-hours, including burning in bottom, which is summarized in Table No. 3.

The operation was carried on in the same way as with the acid method with the exception that the heat was held under a desulphurizing slag for varying periods to determine the possibilities of sulphur reduction. Typical analyses of the various grades of iron produced on the basic hearth are given in Table No. 4.

The result of this experience with the basic process leads to the following conclusions:

1. On account of its superior refining possibilities it allows greater flexibility in the selection of raw materials, especially as regards sulphur content.
2. The control of the alloy constituents may be held to limits as close as those with the acid process.
3. The absorption of carbon is accomplished more readily than in the acid process.
4. The refractory cost is slightly higher per ton, which is more than offset by the lower power consumption and cost of raw materials.

Conclusions on Acid and Basic Methods

In general the result of this test with both the acid and basic methods leads to the following conclusions:

1. In order for the production of synthetic pig iron for sale to iron foundries to be possible commercially, the differential between the delivered price of pig iron and the sale value of steel scrap must be greater than the normal spread found in New England. This condition exists in the Middle and Far West, where the freight on pig iron is high and that on scrap prevents its return to the steel-making districts. The process offers commercial possibilities for central stations having excess

off-peak water power so situated that suitable steel scrap is available and in reach of a market for pig iron. The process is adaptable for this purpose in that it is not necessarily continuous but may be operated to accommodate the periods of low load.

2. Synthetic grey iron may be produced in the electric furnace under favorable conditions at a price equal to or lower than that of the better grades of cupola iron.

3. The production of synthetic grey iron for castings offers a field for utilization of off-peak power in cases where the foundry operation can be rearranged so that the molds may be poured off at night.

4. Synthetic grey iron produces castings having physical strength and toughness far in excess of the best cupola iron, and its chemical analysis shows possible reduction of impurities far below the limitations of the cupola.

5. Reports from foundries which used the pig iron produced in this run indicate that the superior quality of synthetic iron is largely lost when the iron is remelted in the cupola.

6. The use of the electric furnace for the production of synthetic iron offers a broad field for further development of irons of composition varying from the accepted standards which have been developed for the cupola product. The various percentages of carbon, silicon, manganese, sulphur and phosphorus which have become standard practice in iron foundries are a compromise between the results desired and the limitations of the melting medium to produce these results. The electric furnace not being subject to the limitations of the cupola in that its atmosphere is reducing rather than oxidizing, the charge is not contaminated by contact with fuel and flux, and, being free from the relatively low limit of temperature, the furnace offers a melting medium of much greater flexibility than the cupola. The last few years have seen considerable interest in the possibilities of the electric furnace for the iron foundry as shown by the discussion before the technical societies, and it has been predicted that the electric furnace will soon occupy a field of importance in the iron foundry industry equal to, or greater than, its present position in the steel foundry.

7. The electric furnace in the iron foundry affords a means for producing small heats of iron of special composition to meet special requirements. It offers a handy means for utilizing the beneficial properties imparted by definite quantities of alloys, such as chromium, nickel and the rarer elements, such as vana-

FIG. 4—BLAST FURNACE PIG IRON — "SCOTCH" BRAND — TOTAL CARBON 3.52; PHOSPHORUS 0.071; MANGANESE 1.03; SULPHUR 0.043; SILICON 2.04—ETCHED, 2 PER CENT NITAL—500 x

FIG. 5—BLAST FURNACE PIG IRON — "THOMAS" BRAND — TOTAL CARBON 3.46; PHOSPHOROUS 0.706; MANGANESE 0.87; SULPHUR 0.019; SILICON 2.30—ETCHED, 2 PER CENT NITAL—500 x

FIG. 6—SYNTHETIC PIG IRON—TOTAL CARBON 3.24; PHOSPHOROUS 0.042; MANGANESE 1.01; SULPHUR 0.047; SILICON 3.23 — ETCHED, 2 PER CENT NITAL—500 x

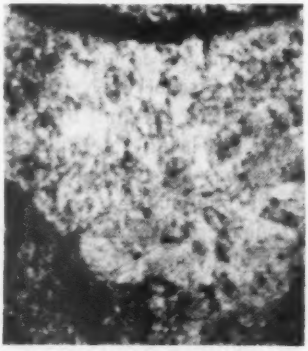


FIG. 7—SYNTHETIC PIG IRON—TOTAL CARBON 3.26; PHOSPHOROUS 0.040; MANGANESE 0.99; SULPHUR 0.039; SILICON 4.20 — ETCHED, 2 PER CENT NITAL—500 x

dium, tungsten and molybdenum. The wider application of the electric furnace to iron foundry problems will, no doubt, result in further research and development of these alloy mixtures in iron in line with the development which has already been made in alloy steels which owes its success largely to the electric furnace.

The process of refining of molten iron delivered from the cupola known as duplexing, has been rather thoroughly discussed

FIG. 8—BLAST FURNACE PIG IRON — "SCOTCH" BRAND — SAME AS FIG. 4—NOT ETCHED —100 x

FIG. 9—BLAST FURNACE PIG IRON — "THOMAS" BRAND — SAME AS FIG. 5—NOT ETCHED— 100 x

FIG. 10—SYNTHETIC PIG IRON, SAME AS FIG. 6—NOT ETCHED— 100 x

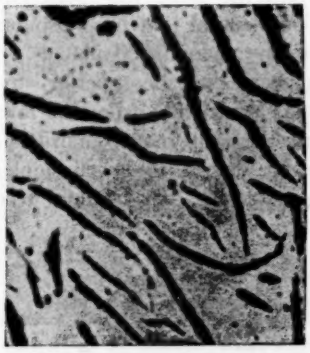


FIG. 11—SYNTHETIC PIG IRON— SAME AS FIG. 7—NOT ETCHED— 100 x

and is being carried out to an increasing extent commercially. Although this process will, no doubt, develop rapidly, owing to its aid in the solution of the sulphur problem, it would seem that the so-called synthetic-iron process also has a certain field of application.

Explanation of Micro-Photographs

The accompanying micro-photographs were made to compare the micro-structure of synthetic pig iron with iron of similar composition produced from the blast furnace. The first group of etched specimens, magnified 500, shows clearly the effect of the high phosphorus content, causing segregation with resultant weakened structure. The specimens of synthetic iron show very plainly the structure of laminar pearlite between the graphite streaks. The second group of polished specimens, magnified 100, show that the distribution of graphite is practically the same in each case.

Superiority Due to Low Phosphorus

Transverse tests taken on standard 1¼-inch round arbitration bars cast from heats to which ferro-phosphorus had been added to give a phosphorus content approximately 0.70 per cent showed an average transverse strength of 3,000 pounds with deflection of 0.14 inch in 12 inches. Bars cast from heats made from the same raw materials under exactly the same conditions, except that no phosphorus was added, showed an average transverse of 6,000 pounds with no sacrifice in deflection. It appears that the superior strength of electric furnace iron results principally from the low phosphorus content, thus avoiding the well known embrittling effect of this element, and to a lesser degree to lower sulphur, more uniform distribution of constituents, and freedom from oxidation.

Synthetic Foundry Iron[1]

By C. E. Williams, C. E. Sims and K. W. B. Worsöe

Last year a paper[2] was read before this body discussing synthetic foundry iron, the information presented being based upon experimental work. Also, a paper[3] on the theoretical aspects of carburization, and another[4] on the use of tin plate scrap were read before the American Electro-chemical Society meetings in 1922 and 1923. Since then synthetic foundry iron production has been established on a commercial basis and in one foundry at least it has been produced continuously for nearly a year. In this foundry, the Wallace Foundry of Vancouver, B. C., the electric furnace has displaced the cupola, except when a quantity of metal beyond the capacity of the electric furnace is required.

In a former paper[5] it was stated that synthetic gray iron could not be made easily in an acid lined furnace. That conclusion was based on laboratory tests in a small acid lined furnace where the arcs were so close to the walls that a slag was invariably formed which effectually prevented good carburization. However, more recent work showed that in a larger acid lined furnace the surface of the metal can be kept free from slag and carburization readily accomplished.

Commercial Production

A three-phase, direct-arc, acid-lined Greene furnace was installed by the Wallace Foundry, Vancouver, B. C., in August, 1923. It has a normal capacity of 3,000 lb. and is somewhat underpowered, drawing a maximum of 600 K.W. This furnace was installed for the double purpose of making synthetic iron and melting steel, thereby taking advantage of the peculiar eco-

[1]Published by permission of the Director, Bureau of Mines.

[2]Sims, C. E., Williams, C. E., and Larsen, B. M., *Manufacture of synthetic foundry iron in the electric furnace:* Trans. American Foundrymen's Association, Vol. 31, 1923, pp. 154-156.

[3]Williams, C. E., and Sims, C. E., *A study of carburization in the manufacture of synthetic cast iron:* Trans. American Electrochemical Society, Vol. XLI, 1922, pp. 63-86.

[4]Williams, C. E., Sims, C. E., and Newhall, C. A., *Electric furnace detinning and production of synthetic gray iron from tin plate scrap:* Trans. American Electrochemical Society, Vol. XLIII, 1923, p. 191.

[5]Sims, C. E., Williams, C. E., and Larsen, B. M., work cited.

nomic conditions existing on the north Pacific coast. These conditions include a high cost of pig iron, gray iron scrap, and foundry coke, with a plentiful supply of comparatively cheap steel scrap. The high cost of pig iron necessitates the use of a cupola mixture containing a large amount of scrap, often as high as 80 per cent, with poor quality iron as a result. These conditions, together with a moderate power rate, made the prospects of producing synthetic gray iron attractive. The early efforts, although successful in producing gray iron, were not satisfactory from an economic standpoint. But later, working in cooperation with the staff of the Northwest Experiment Station of the Bureau of Mines, principles learned during experimental work at the latter place were applied, and the production of synthetic gray iron was put on a practical and economical operating basis. The cost of iron in the ladle was reduced to three-quarters of the original figure, and, in fact, to three-quarters of the cost of cupola metal in the ladle. As before mentioned, the production of synthetic gray iron has eliminated the use of the cupola entirely except when large quantities of metal are needed. The furnace is operated 11 to 13 hours per day and in that time turns out two heats of steel and two heats of gray iron, normally 3,500 to 4,000 pounds per heat. The low power input to the furnace is responsible for the long time required per heat. Mild steel, chrome steel, manganese steel, and white or gray cast iron are produced in alternate or successive heats according to the demand from the casting floor. When ordinary care is exercised, mild steel is produced directly after a gray iron melt, without difficulty.

Materials

Steel and Iron Scrap

Miscellaneous steel scrap of any kind that is small enough to be charged into the furnace, wrought iron, malleable iron scrap, and cast iron scrap, including material that is badly burned or oxidized or otherwise unfitted for use in the cupola are all satisfactory materials for conversion to synthetic iron. Because of the large content of carbon in the charge, the process is strongly reducing in character so that nearly all the alloying metals present in the charge are recovered in the product, and iron oxide is

reduced to metal. Badly rusted steel or iron turnings can be melted satisfactorily when extra carbon is mixed with the charge to reduce the iron oxide present. Scrap that is bulky and hard to handle, such as sheet or tin plate scrap should be compressed into small bales for easy charging. High-silicon acid-resisting iron scrap was found to be thoroughly satisfactory for introducing the required silicon. The problem of raw materials supply thus depends on relative cheapness, ease of handling, need of properly controlling composition, and the desirability of using up all waste scrap materials.

Carburizers

One of the most important factors in the production of synthetic gray iron is the use of a high quality carburizer. This was emphasized in a previous paper in our discussion of experimental data but was brought out more forcibly in the commercial operation. The essential requirement of a high quality carburizer is low ash content. The lower the ash the faster the carbon dissolves and the smaller the amount of carburizer required. The carburizer first used at the Wallace Foundry was a foundry coke containing from 14 to 15 per cent ash. Later, coal-tar coke similar to petroleum coke and containing less than 1 per cent of ash was used. The average of 18 melts using high ash coke and of 18 using the purer carbon gave the following results.

	Power consumption, KWH per ton	Amount of carburizer per ton in lbs.
Using coke (15 per cent ash).....	798	206
Using tar still residue (1 per cent ash)	659	103

When dirty coke screenings were used the power consumption was 1,060 KWH per ton. The use of the better carburizer reduces the power consumption, the amount of carburizer required, the time of a run, and the disagreeable labor of skimming, and also increases refractory life, all of which have a direct bearing on the cost of operation. The carburizer has a much greater influence on the life of the refractories than might be suspected. The efficiency with which the heat of the arcs is transferred to the metal decreases as the thickness of the layer of carbon on the metal increases. When the layer is too thick the arc plays between the electrodes and the upper surface of the carbon. The

metal is then protected by the thick layer of carburizer and the heat of the arcs is radiated to the walls and roof, which may become overheated. In extreme cases the walls and roof have been heated to dripping before the metal was heated to the desired temperature. To eliminate this trouble the carburizer should be added in several portions at intervals, the first portion being skimmed off before the second is added. If the carburizer is not fine enough the large pieces have a tendency to pile up under each electrode with the same resultant effect as too thick a layer. But if the carbon is finely crushed, say to pass a four mesh screen, the blowing effect of the arc tends to scatter the particles and allows the arc to penetrate to the metal surface. Such practice will make possible a minimum of overheating of walls and roof, and better refractory service.

Operations

In producing synthetic foundry iron, the operations are simple and practical, and can be standardized as readily as in steel melting. The charge is made up in a manner similar to a steel charge containing both light and heavy scrap that will pack well in the furnace. Ordinarily from 20 to 25 per cent of gray iron back stock will be charged with the steel scrap. In charging, the bottom of the furnace is first completely covered with scrap. The carburizer is spread over this and the rest of the scrap added on top. It is well to have the carburizer at the bottom of the charge so that the melting steel will trickle down through it, but, if steel is to be made in the same furnace, it is important that the carburizer be not put directly on the bottom of the furnace for it may remain there and contaminate the following steel heat. The pouring spout is luted up except for a small opening through which samples may be poured. After the furnace is charged, melting is conducted as rapidly as possible in order to gain economy of time and power. In short, all methods that work for efficiency in other electric furnace operations apply equally well in this one. Ferro silicon and ferro manganese are added either with the charge or immediately after it is melted. About thirty minutes after the charge is all melted a small ladleful of metal is cast into a wedge or tapered

bar of some kind, allowed to cool to a bright red heat and then quenched and broken for examination of the fracture. If the section of the test bar equal to the thinnest section to be cast is gray, then the charge is ready to pour. If it is not gray enough the run is continued and a similar sample taken after about twenty minutes or at the judgment of the operator. Before the metal is poured the charging door is opened and as much of the carburizer is skimmed off as possible; what little remains runs out with the metal and does not interfere with the following heat.

Composition of Product

Iron products of any desired composition can be made easily. The sulphur and phosphorus contents will ordinarily be limited to the amount that was in the scrap charged. Neither can be controlled in an acid furnace except by control of charge composition. The amount of silicon and manganese in the final metal will be the total of the silicon and manganese in the scrap plus that added as ferro silicon and ferro manganese; practically 100 per cent recovery of these elements can be depended upon. The carbon is added in excess and is continually absorbed by the iron until the run is stopped or the carburizer removed. By examination of periodic samples the carbon content can be closely controlled. Ordinarily only enough carbon must be introduced to produce gray iron in the thinnest sections to be cast. An exception to this rule is necessary when high fluidity is required. Synthetic gray iron being phosphorus free will not have the fluidity given by phosphorus to ordinary gray iron. Fluidity can be obtained by superheating which is easily done in the electric furnace, but iron that is too hot may produce rough-surfaced, difficultly-cleaned castings. Fluidity may also be obtained by increasing the carbon and silicon content. Hence, where a smooth-surface is important, as in stove plate castings, a compromise must be struck between high carbon and high silicon on one hand and high temperature on the other to obtain the desired fluidity or "life" and still have a smooth casting. In this way fluidity is obtained without sacrificing strength as is done when high phosphorus iron is used.

The sulphur content of synthetic iron will be very low. It is generally accepted that low sulphur irons are stronger and more readily produce flawless castings. But other advantages are apparent for synthetic gray iron. Ordinarily excess silicon is used to offset the hardening effect of sulphur in cast iron; but this is not necessary with synthetic iron which is relatively free from sulphur. Large manganese additions usually required in cupola iron to help offset the effects of sulphur and the oxidizing action of the cupola gases are not necessary in synthetic iron. Ordinarily 4 or 5 lbs. of ferromanganese per ton of iron is added.

Other economies readily occur to the operator, such as the possibility of producing two grades of iron from one heat. For example, suppose both heavy and light section castings must be poured from the same charge. The melter would bring the composition of the iron to 3.0-3.25 per cent carbon and 1 per cent silicon. This iron would produce soft, gray, heavy sections but hard, white, thin sections. Hence, to avoid adding silicon to the entire charge simply to obtain gray iron in the light sections, the metal of the above composition is poured into the heavy-section castings and ferrosilicon is added to the metal left in the furnace to raise the silicon to 2 per cent so that the light sections made from it will be gray.

Advantages of Synthetic Iron Production

Some of the advantages of synthetic foundry iron production are:

(1) One furnace can be used to supply all of a foundry's requirements for iron and steel.

(2) An electric steel furnace can thereby be kept in operation during periods when it might otherwise be idle. By keeping an electric furnace in continuous operation, the labor is kept usefully employed, the heat of the furnace is conserved, refractory life is extended, and overhead charges are reduced. Also, when more power is consumed a lower rate is usually obtainable. Therefore, even under conditions where synthetic iron production would not alone be economical, it might be profitable

in conjunction with steel production because of the possibility of reducing the costs of the latter operation.

(3) A great variety of steel and iron scrap can be used to make the same product and a variety of products can be made from the same materials. Scrap is usually purchased locally and the foundryman can buy and use what is at hand without shopping around for special materials. The production of synthetic iron simplifies the purchase of steel melting scrap. For instance, to make acid steel, selected scrap is required for which a higher price must be paid than for general scrap. But if, in addition to steel, synthetic iron is made, miscellaneous steel scrap may be purchased at a minimum price and the foundryman can do his own sorting, using the best scrap for acid steel.

(4) Synthetic iron may be tested and adjusted for composition and temperature before it is poured, thus assuring good castings. Moreover, if the pouring crew is not ready, the metal can be kept hot as long as necessary.

(5) A superior iron is obtained. Electric furnace iron can be made about twice as strong as ordinary cupola iron. Transverse strengths of 5,000 to 6,000 lbs. with deflections as high as 0.365 inches on standard bars of synthetic gray iron have been repeatedly obtained. Tensile strengths above 40,000 pounds per square inch are common. Although no figures are available, one of the outstanding characteristics of synthetic gray iron is its resistance to impact or shock. These advantages in strength and toughness are due partly to the low sulphur and phosphorus contents, and partly to the physical structure of the iron. The fracture shows this structure to be fine grained and dense. The graphite exists in such small flakes that a piece of synthetic iron having the same graphitic carbon content as a piece of cupola iron will appear to contain less graphite. Although it looks whiter than cupola iron, synthetic iron is soft and easily machined. A coarse grained synthetic iron can only be obtained when the carbon and the silicon contents are high. The ordinary synthetic iron is at least equivalent in strength to the so-called high test irons and semi-steels of the cupola.

(6) Practically any kind of ferrous scrap can be used, thus providing a means for industrial plants to utilize the scrap they

produce instead of shipping it away at an economic loss. Besides steel scrap, which may be carburized to gray iron, such gray iron scrap as borings and turnings may be used profitably. Although some failures have been reported in attempts to melt gray iron turnings, we have been successful in melting them in both the experimental and commercial furnace with no more trouble than with other materials. In 1911 and 1912 C. A. Hansen[6] melted over 21 tons of cast iron borings in an electric furnace with a total loss of less than 3 per cent of the metal. He estimated from his results that borings could be melted with a power consumption of 500 KWH per ton. Badly corroded or oxidized borings can be melted easily if carbon is mixed with the charge to reduce the iron oxide which otherwise causes trouble.

The production of synthetic cast iron in the electric furnace is useful in such places as the large non-ferrous smelters and mills, especially those in the western states. Although they usually produce a large quantity of iron and steel scrap, they buy high priced pig iron to supply their foundries. By making synthetic iron the use of pig iron could be dispensed with.

Many ore concentration plants consume a large tonnage of steel and iron balls for fine grinding. Satisfactory white iron balls could be made economically in the electric furnace from steel scrap. During experimental work on synthetic foundry iron, products were obtained which, while too hard to be drilled with a high speed steel drill, were not brittle like ordinary white iron but were slightly malleable. Such a composition should make an excellent mill ball material.

Other Types of Furnaces

A short campaign was run in a Detroit foundry using a Detroit indirect arc rocking furnace of one-ton capacity. The runs were uniformly successful in producing good gray iron from structural steel scrap using crushed foundry coke as a carburizer. The consistently rapid carburization is attributed to the thorough mixing and intimate contact of metal and coke caused by the rocking motion of the furnace. A carbon content of over four per cent was easily obtained by continuing the run

[6]Work not published.

sufficiently long. The metal was usually poured when about 3.5 per cent carbon was reached, which was obtained about one-half hour after all the metal was melted. The power consumption on one ton lots was about 700 KWH per ton but it is thought that this figure can be further reduced.

The indirect arc furnace has the advantage of quick carburizing and of being charged and cleaned easily.

The main disadvantage of the indirect arc furnace lies in the inability of refractory materials to stand up for a long time at the high temperatures required for making gray iron. It isn't the high temperature alone because the final temperature is no greater than in other types of furnace, but during the melting period before the rocking is commenced the part serving as roof is acted on severely by the direct radiation from the arc. This necessitates slow melting if the unprotected parts of the lining are not to be damaged. An expedient resorted to was that of charging some gray iron along with the steel scrap instead of using an all-steel charge. This caused the initial melting to start at a lower temperature and enabled the rocking to be started sooner. A more refractory lining would solve the main trouble with this type of furnace. The high breakage loss of electrodes is also a disadvantage of this furnace. As yet no tests have been made in an induction furnace, but theoretical considerations would indicate that this type of furnace would be very successful. The movement of the metal should give rapid distribution of carbon, and the lower power consumption and absence of electrodes show important economical advantages for the induction furnace.

Summary

The production of synthetic gray iron from steel scrap has become a successful commercial practice in at least one foundry. At first produced there almost as an experiment, it has now replaced the cupola product entirely. Under the existing conditions, synthetic gray iron is being produced at a lower cost than cupola iron, and at the same time a greatly superior iron is being obtained. Observations on this commercial operation have shown that conclusions drawn from experimental work reported in earlier papers were fully justified, except that an acid lined furnace is satisfactory.

Discussion—Electric Furnace Cast Iron

G. K. ELLIOTT: I think my discussion would be a little better if it came after a few questions had been asked and the discussion really opened wide. But it seems to me that when this is discussed one of the first things that should be understood by the group is the difference between these two furnace linings that we are speaking about: the acid and the basic lining. If somebody does not describe and emphasize these differences, I believe that a good many who listen to the discussion will become very much confused, because we do things in a basic furnace which are impossible in an acid furnace and, to a lesser extent, vice versa. So I shall, very briefly, try to outline for you the difference between these two operations as applied to gray iron.

Presumably you all understand that an acid furnace is really an electric furnace with an acid hearth. By an acid hearth I mean a hearth which, chemically speaking, is acid, or silica, as we commonly call it; in other words, an electric furnace has a silica hearth or a silica body. The side walls and roof also are silica. The basic furnace, on the other hand, as we chemists would tell you, has you might say an alkaline or a basic bottom, one which chemically has a basic reaction. The bottom in such case is formed from oxides of magnesium, or magnesium and calcium. If it is pure magnesium, the bottom is usually a magnesite bottom, really magnesium oxide, or possibly it is built up of both magnesite and dolomite, which is you might say mixed oxides of magnesium and calcium. The side walls and roof of the basic furnace are somewhat similar to that of the acid furnace, that is, they are of silica brick, but the metal is in contact with the hearth, you understand, and that is where the reactions take place.

The slags differ in the two furnaces. The acid furnace is operated with an acid slag; that is, one in which the acid influence predominates or one which is high in silica. The basic furnace is operated by the basic slag, the main constituent of which is lime—calcium oxide. So much for the hearth and slags of the two furnaces.

Now, the elements are affected in a different way in these two furnaces, and I will very briefly try to describe to you the difference. The most important in our gray iron is the carbon. The difference is not so great between the two, except for the fact that a basic furnace is quite frequently operated with a calcium carbide slag, that is, rich in calcium carbide, and it naturally carries considerable carbon, and some of this carbon naturally enough will be worked into the iron. The basic gray iron naturally runs probably a little higher in carbon unless particular attention is paid to recarburizing the acid metal.

Probably our next important element is silicon, and here we find quite a difference. You can readily foresee that for yourself. In the acid furnace with its silica slag and silica bottom, there is apt to be considerable pick up of silicon, especially if the furnace is run high. In the basic furnace, on the other hand, there is apt to be a drop in silicon instead of reaction between the base and the acid.

Next take the element manganese, which is quite important in this electric furnace metallurgy. In the acid furnace there is a very decided drop in manganese. I find that most of the parties who are writing on electric furnaces really neglect to emphasize this point. There is a very decided drop, which has to be taken care of at the end of the heat by sufficient additions of manganese in the form of ferro-manganese or spiegel. On the other hand, in the basic furnace there is absolutely no loss of manganese; whatever manganese is put in that furnace comes out of it, that is, unless you try to do that which you should not do, follow steel practice and run an oxidizing slag at a certain point. You would lose your increase; but if you operate it as you ought to operate it you will have absolutely no loss of manganese. This is quite an important item.

Then take the element of phosphorous. There has been considerable said about this in the papers this morning. In the acid furnace there will be no change, no perceptible change in the phosphorous. Whatever phosphorous you put in you can look to find in the finished product. In the basic furnace, of course, those of you who are familiar with basic operation will immediately say that you can take out the phosphorous in a basic furnace, which is entirely true; but it is also utterly impracticable in the case of gray iron. Phosphorous may be taken out under oxidizing conditions, under an oxidizing slag, which is also, in fact, done in the case of steel. In the case of gray iron as soon as you try to operate the furnace under oxidizing conditions you will find a number of elements there in large quantity which are susceptible to this oxidation and which must be taken out before you can make your oxidation touch the phosphorous that you are after. The elements I refer to are the carbon, silicon and manganese. You take the carbon out and you have steel. It means then that if you are going to dephosphorize gray iron in an electric furnace, you have to make it into steel and dephosphorize it and then make it back into gray iron, which, of course, is entirely out of the question.

Then take the fifth of our five elements: the sulphur. In the acid furnace, operating under normal acid conditions, you have no reduction in sulphur. Of course, it is possible by very close operation, but you may be jeopardizing your bottom somewhat to run your slag fairly high in calcium and take out some of the sulphur. Ordinarily speaking, however, your sulphur is unaffected in the acid furnace. In the basic furnace the sulphur comes out with remarkable ease. If you

have a truly basic slag and have some carbon in it, and you have it in a deoxidizing condition, you can't keep the sulphur from coming out. One of the easiest things in the world to do is to take out sulphur in a basic bottom and acid furnace—or electric furnace.

Another element which chemists never analyze for and don't like to talk about very much, but which foundrymen insist on getting back to, is that of oxygen. We attribute a great many troubles, which we cannot lay to the door of any other element, to oxygen, and I think in most cases we justly do so. The acid furnace has at least a neutral atmosphere; that is, there should be no tendency to oxidize except around these foundries where you have a nervous melter or a rather ignorant one and a lot of curious people opening the door to see what it looks like inside. Of course, if that is done there is a draft of fresh air over the furnace, which as you know carries a large percentage of oxygen, then you have some oxidation. But if the furnace is regulated properly, you should have no appreciable oxidation. In the basic furnace, of course, your conditions are more than neutral; they are absolutely reducing; and not only reducing but most emphatically reducing. I believe there are no metallurgical conditions reducing to the same extent as are those which exist in a properly operated basic electric furnace.

I think, gentlemen, that I have accomplished what I set out to do, at least to outline for you the difference between these two furnaces, and I would like now to leave the discussion to some of you gentlemen.

CHAIRMAN L. L. ANTHES: This is what might be called a transitional period in the gray iron practice. A little of the terminology which is applicable to gray iron in the electric furnace is terminology to which steel operators are quite used; they understand it very thoroughly; but to the ordinary gray iron foundryman a lot of these terms are more or less obscure, and I felt that it was only justice to the large number of gray iron men who are here to have Mr. Elliott explain some of these features. As you know, conditions have been rapidly changing all over this continent. We have what are known as high railroad freight rates, which have a tendency to localize business in many quarters, and this condition has raised an economic question. Those who are manufacturing gray iron commodities, under strong competing conditions, desire to bring down their costs as low as possible. I believe that in this transition from the cupola to the electric furnace for gray iron there are many possibilities, and it is our desire that those who are seriously contemplating taking advantage of certain economic factors will receive as much information as can possibly be given them within a short time and will be in a position to ask for further information if it is desired. I will now throw the meeting open for general discussion. It is a very, very important question,

gentlemen, this is a milestone in foundry practice and we would like to get off for a good start, and we can only do that by people showing an interest in a discussion of these very valuable papers which have been delivered this morning. I am quite sure that those who have given the papers will be far more satisfied if they feel that the general meeting shows an interest in these papers by asking questions.

G. B. LAMB: Our plant is located very close to the place where Mr. Williams is carrying on his experiments. We are running a steel foundry primarily, making our own steel castings. We require them to be of very good quality of low carbon steel, because they have to be very light and strong, but we do not have enough low carbon steel to run our steel foundry to capacity. Therefore we want to fill up with cast iron work. Our cast iron is strictly jobbing and not manufacturing, and we are confronted with this condition: we pay 1.33 per kilowatt-hour demand; we pay a cent and a quarter per kilowatt hour used. The largest one of those two charges is the one we pay for, and therefore if our consumption is lower than our demand charge we might just as well keep on using any amount of power. As it worked out at our plant, it has been proven that this year we have paid entirely for demand, so any consumption does not cost us anything over our demand. The scrap we are using for making cast iron is car wheel scrap, chilled car wheel scrap, and we pay $10 a ton for it. We get it from one of the logging companies and have to pay very little freight. The way it works out is this: when a car goes up to camp with material, it then comes back to our plant with car wheels. The condition of this scrap as we receive it at the plant is 2 per cent carbon on an average, .75 silicon, sulphur about .10. To make good cast iron we have to raise the silicon and carbon. It is not synthetic cast iron that we have to make, but we have to use the same process. We have found that you can raise your carbon to 2.5 without any trouble at all, but over that you have to fight for it. To start with, we put our carbon on the bottom of the furnace and our cast iron on top, but since we are making steel on the next heat we have to get all of that carbon out. We found there would be a contamination of our steel by doing that. So we had to stop this practice. What we do now is to charge our cast iron scrap, and then after it is just melted we add our carburizing material.

We have tried different materials. To begin with, we used plain coke and did not get satisfaction. With slag, and adding a new batch of coke again, we were able to raise it some, but it was not satisfactory. That was just ordinary coke; it was not coal tar coke. What we have finally determined on is as much graphite as we can. The first heat we put in was plain coke, and we slagged that off and then put graphite on. The graphite we obtained from burned electrodes. Our policy in regard to the use of electrodes is that when one is broken

and cannot be used in the furnace again, or a short piece, it is ground up to make our graphite.

We have, however, no trouble with our linings burning up in the cast iron heats. We make the steel heat first, and the last thing in the day we make our cast iron. The charging of the cast iron on the hot furnace melts it very rapidly and we practically consume no more additional power. The power never goes over 600 kilowatts per ton; usually is lower than that.

Silicon has been a problem with us, too. It is not a problem to get it in, we can do that all right, but it is the cost. We have to keep the furnace turning out cast iron to compete with cupolas; we can't sell it on quality, it is simply a matter of economy. We have not as yet determined what is the best way of adding our silicon. We have added ferro-silicon, but it resulted in as high as 50 per cent loss in recovery. I don't know why. We tried out the ferro-silicon on the clear bath to the metal, and by that method we got our worst loss. We tried adding it on coke, and that seems to have proved the best method of adding the ferro-silicon for us. We had to allow sufficient time for melting and had to stir it pretty thoroughly to get it down in. It seems that the silicon will partially melt and stay in the slag and won't go down. I don't want you to understand that this is a real slag that we have there. It is merely coke and material that is used. We had no slag in the material.

It is necessary to clean the furnace for the next steel heat in order that we have no carbon left. As I said before, when the coke was added to the bottom, it seems that that coke was pushed down into it, the bottom when we started being pretty soft, and the coke seemed to adhere to it, and we couldn't get it out.

We tried putting the ore on the bottom. Of course, that was nearly ruinous. We now add no ore whatsoever. After the cast iron is poured we take a ravel and ravel all loose material out of the furnace. There should be no cast iron in the furnace, and it is necessary to ravel off practically all of the soft material. What is left usually won't amount to more than a shovelful. Then we add a little bit of sand, just throw sand over it, sprinkle it over; in this way we have not been troubled at all with carbon contamination. The carbon steel we are making is about 20 to 24 point carbon, and on the steel heat following the iron we do not add any ore. We are using a low carbon scrap and carry on our steel heat exactly as though there had not been a cast iron heat previously.

CHAIRMAN L. L. ANTHES: Gentlemen, it is very satisfactory to have people get up who have had actual experience in the carrying

on of work in actual foundry practice, not in an experimental way. It is information such as that that we are very keen to receive. Now, I think you have had considerable information as to the actual practice of the steel furnace and gray iron, and it is quite natural that there will be some questions that some of the members desire to ask.

H. B. MAY: I would like to ask the gentleman who last spoke just what if any bad effect he finds in the steel after using cast iron? We tried out a number of heats that way—although we haven't gone into it very thoroughly, but we expect to in the near future—and we have found considerable trouble in our steel heat. They were apparently wild, hard to control. Possibly we did not clean the furnace thoroughly, but we cleaned the best that we could by taking all of the soft material out, and still we had a wild heat. Practically every heat following our cast iron heat was hard to control, and unless we held them for 30 or 40 minutes we would have a wild heat.

G. B. LAMB: We had some trouble to begin with in that manner, steel following cast iron. Where we ran three cast iron heats in a row we were troubled with high carbon, although we cleaned the bottom as usual. We have no trouble with high carbon in our steel heat or anything of that sort that has been detrimental to the steel. It has been entirely a matter of carbon in our steel heat following iron, and we have succeeded by cleaning the bottom thoroughly and doing away with slag.

H. B. MAY: The practice then is to melt only one iron heat and then follow with the steel heat?

G. B. LAMB: Yes. In regard to the three heats it might be well to state that on the following steel heat after our three iron heats we had to use coke, and that caused wildness in our steel. The ore that we are getting at our plant is very poor and it takes a gunnysack full, so we can't compare our practice in that respect with any practice in other places in the country where they have good ore.

H. B. MAY: You found that from an economical standpoint you could run your cast iron through your electric furnace very satisfactorily?

G. B. LAMB: Yes. We had the cupola standing idle and figured that on account of our cheap power, or practically no cost for power, we could afford to do it.

H. B. MAY: I think what would apply to the difference in the ore would naturally apply to the difference in coke. I was very interested to hear the discussion as to the use of coke, and in that respect we must all take into account the fact that in different sections of our country we have different grades of coke, so that when we use the general term "coke" it might be very misleading, because in one section they may

have inferior coke, while in another section it may be a very high-class coke, particularly so in central United States and our district around here, where the preponderance of coke used in foundry practice is of the by-product oven quality. Mr. Williams spoke of an ash content of 10 or 15 per cent, and our coke produced in the central United States, in the by-product ovens, will all average around 8 per cent, so that we get an exceptionally low ash coke, high in carbon. Mr. Williams spoke about the use of petroleum carbon. I would be interested and it would be an interesting thing for the members to know which process of the petroleum carbon was used in making this test. It might not be generally known that there are two processes of petroleum carbon. The Standard Oil Company, of course, is one of the largest producers of petroleum carbon coke, which is made by one process, and the Sinclair Refining Comapny, another oil company, are producers of another petroleum carbon coke, under another process. There is a vast difference between those two petroleum carbons. The opinion seems to prevail at this time that the low pressure coke made by the Sinclair Oil Company and other concerns is the best of the two products. That, by the way, removes the possibility of petroleum carbon in that low process coke being a commercial possibilty, because of its scarcity. The scarcity has been somewhat recent, due to the fact that our radio came into its own in the last year or year and a half. When it first started out it was a wet battery automobile proposition, but now has generally switched around to dry batteries. As dry batteries are made from this petroleum carbon, the demand for that product today practically meets the supply. So that if it is a low process product that we are talking about, it is a high cost, as Mr. Williams said. He said that even at the high cost the product was worth all it cost, but it is getting scarcer. Down East, of course, in the New England fields, we have by-product coke plants, at Providence and other points, that make a very good by-product.

CHAIRMAN L. L. ANTHES: Mr. Lamb, a few minutes ago you said that the cupolas were practically now lying idle. You might give the tonnage, so as to give the members an idea about the capacity which is being used.

G. B. LAMB: Our practice at present is 2,400 pounds of cast iron in the last heat. When we are running the cupola that requires that we save up our molds for practically a week's period. The cast iron, you might say, is just used to fill in.

H. B. SWAN: I would like to ask if in the making of cast iron in the sand molds whether with the higher heat you get in the electric furnace you get a finer dissemination of the graphite when you get a finer grade of castings?

G. K. ELLIOTT: We started this practice in 1917 and we still continue it. Those of you who do not know our product, I will say for

your benefit that it is submitted to the pressure test, and, of course, the picture or the grain of the metal is of the utmost importance. Our experience was that the electric furnace did give us a closer grained product and quite possibly a more uniform distribution of the carbon, although I am free to admit that this result was probably also partly obtained by the fact that by taking comparatively small quantities of iron and treating them in the electric furnace for a definite set of castings we could adjust the entire analysis so as to fit a given casting, which is an advantage, even if you could do that in a cupola. The two effects were together at the same time, so I was not able to separate one from the other, but my opinion is, and I feel reasonably sure that I am correct, that it does close the grain of the metal.

C. E. WILLIAMS: We found that comparing the electric furnace cast iron and the cupola cast iron, of the same carbon and silicon content, that the cupola iron is misleading, in that the carbon is much lower than it really is. I think that is the real reason for the superior strength of electric furnace iron over cupola cast iron.

As regards the point about coke, I think that since the tonnage of the coke required for any synthetic iron operation is so small, relatively speaking, that you will be able to count on a pretty good supply of a carbon and ash free coke. Almost in any big district there are coal tar distillation plants in connection with most plants making gas, which produce this coal tar residue, as it is called, in fairly large quantities, and that stuff can be obtained in almost any city that I have investigated. That's one type of carbon that ordinarily isn't thought of in connection with this work. The matter of various types of petroleum coke I don't think matters, as long as the silicon content is watched. The main object is to get an ash as low as possible. It doesn't matter what type of carbon is used. For example, most electric furnace plants have a large production of carbon electrodes or graphite electrodes, which can be smashed up by the men during their spare time, and such material makes an ideal carburizer.

The matter of carbon left after a cast iron heat, contaminating the steel, is one largely of preventing the carbon going against the furnace bottom. We found at the foundry at Vancouver that by charging the portion of the steel scrap first, covering the bottom completely, and then adding the carbon and adding the rest of the steel, about one-third going on the bottom before the carbon is added, then the rest, that no carbon remained in the furnace when the charge was poured. All of the carbon would rise up to the top by the time the steel was entirely melted and could be scraped off, and after being scraped off would run out of the metal. In the past three months there has been absolutely no trouble in high carbon steel.

D. J. KENNEDY: I might just say that during the years 1916, 1917 and 1918 low cost pig was at a very high price. At that time our people in-

stalled an electric furnace for the production of low cost pig, or pig to take the place of low cost pig, and during that period we used in the neighborhood of 500 tons of pig iron for synthetic pig. We started it off with a carbon block bottom in the furnace. That was found to be very unsatisfactory. Finally we wound up with a lime bottom, centered in. Our carbons were controlled, at least latterly, by using a wood charcoal. At that time the charcoal was mixed on the floor with the shell steel turnings, turned over two or three times with shovels, and put in the furnace. We had no trouble at that time with getting the required carbon, but in the earlier stages we had a great deal of trouble. That was the final practice and it worked very satisfactorily. At that time low cost pig iron was costing, delivered, in the neighborhood of $65 to $70 a gross ton, and we found that our production costs on the synthetic iron were running around $45 a gross ton. But we discontinued this afterwards because the cost of low price iron came down to the cost of synthetic iron. I just wanted to mention the fact that we found charcoal coke was very satisfactory and that we attribute that principally to the low ash content of the wood charcoal.

A MEMBER: We found that when we ran into this question of pouring temperatures we began to get trouble. Instead of running gray iron we were running white iron. Would that be due to that lack of silicon content?

C. E. WILLIAMS: Two chaps who were investigating the hardening or carburizing found out that the carbon dioxide and carbon monoxide assisted in the precipitation of carbon, evidently acting as a catylitic agent, and that explained this phenomena. Then I noticed in gray iron that the electric furnace gray iron seemed to require a little more silicon for a given softness or hardness than did the cupola, and I figured that the electric furnace iron had been shut clear of this catylitic, which accelerated and aided the precipitation of graphite. That may have some bearing upon the trouble Mr. Moore has encountered, but possibly he is running his silicon too low. Of course, pouring hot increases the danger of having a chill.

A MEMBER: I would like to inquire about carbonizing a low carbon steel up to 2.5 per cent, about how much excess carbon would have to be added.

C. E. WILLIAMS: We found from tests that almost 100 per cent recovery of the carbon could be made. However, in order to save time, it is more economical to use a fairly low excess of carbon than to try to get a big recovery of carbon. In order to get a 3.5 per cent carbon we found that we might use 5 per cent of carbon.

The Mechanism of Graphitization of White Cast Iron and Its Application to the Malleablizing Process

By Anson Hayes, W. J. Diederichs and H. E. Flanders, Iowa State College, Ames, Iowa

A study of the literature prior to recent date (about 1920) will show an almost complete absence of investigations, the primary purpose of which was to shorten the time required for graphitization. There seems to have been little study, also, of the material which results from such shortened processes or of the material which results when graphitization is only partially completed. Investigations seem, in the main, to have been conducted to refine the original process. The result is that the process used today is fundamentally identical with the original, though there have been epochal improvements made in the equipment used and in the chemical and temperature control of the process. This resulted in a great improvement in the quality and uniformity of the product.

Intensive scientific study of the malleablizing process and the formulation of theories concerning the graphitizing mechanism are of very recent origin. Necessarily, investigations to shorten the annealing time and to produce partially graphitized materials (materials which will hereafter in this paper be designated as intermediate products) could not be intelligently pursued until the mechanism of graphitization was rather thoroughly understood.

The purpose of this paper is to report work done at Iowa State College which, in combination with reports of work of other investigators, resulted in a theory for the mechanism of

(Note: This paper consists of a portion of a bulletin by the same title which will soon be published by the Engineering Experiment Station of Iowa State College and it is here presented by permission of the Station. Certain phases of this work have also appeared at various times in Transactions of the Amer. Soc. for Steel Treating.)

complete graphitization of white iron and also to report results of the application of this theory to the problems of shortening the annealing cycle and the production of intermediate products.

Theory for the Mechanism of Complete Graphitization

It has been suggested by a number of investigators that the solubility of carbon from cementite (Fe_3C) in gamma iron is greater than that of carbon from carbon (C). This suggestion is in conformity with the known fact that cementite breaks down into carbon and solid solution at temperatures above the

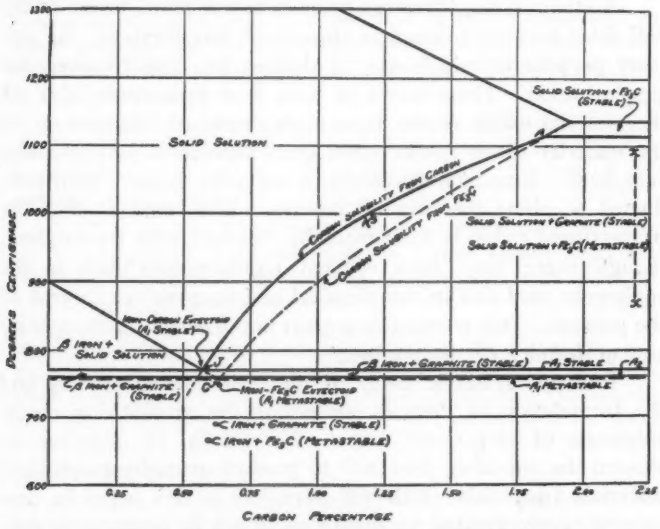


FIG. 1 – CONSTITUTIONAL DIAGRAM FOR IRON-CARBON ALLOYS OF WHITE CAST IRON COMPOSITION

FIG. 1—CONSTITUTIONAL DIAGRAM FOR IRON-CARBON ALLOYS OF WHITE IRON COMPOSITION

lower critical range. This is equivalent to stating that cementite is metastable at these temperatures. What happens on cooling slowly through the lower critical range is a more complicated problem and has been a point of considerable dispute. To clarify the following discussion we will trace out these mecha-

nisms on the constitutional diagram for an alloy of white iron composition, shown in Fig. 1.*

Assume that we heat a white cast iron of composition X-X to 1,000 degrees Cent. On passing the critical temperature the ground mass of pearlite becomes solid solution and the absorption of massive cementite begins. This absorption of cementite continues as the temperature rises, due to the fact that its solubility increases with temperature. Upon holding at 1,000 degrees Cent. massive cementite continues to be absorbed and at the same time carbon is being deposited, since the solubility in solid solution of carbon from carbon is less than that of carbon from cementite. Unless the rise in temperature beyond the critical is rapid the foregoing action was also in operation during the heating period, before the maximum temperature was reached. The breaking down process at the high temperature will continue until equilibrium is reached between carbon and solid solution as indicated by the point K. This process is comparatively rapid due to the high temperature. The same action occurs if other temperatures above the critical range are used,

*Fig. 1 is a modification of the diagram for pure iron carbon alloys to represent the graphitizing behavior of white iron of approximately one per cent silicon. For the temperatures of J and C the extrapolation values of Flanders and Moore[8] were taken. They are 771 degrees Cent. and 759 degrees Cent. respectively. The equilibrium carbon concentration was taken from Schwartz[3] as 0.57 per cent. The carbon concentration at C has not been determined experimentally. Its value was obtained by drawing a line from the A_1 point for pure iron to the point J and continuing it until the temperature 759 degrees Cent. was reached. This gives a value of 0.64 per cent carbon for pearlite. This is in conformity with the observations of Charpy[10] that the carbon content of pearlite decreases as the silicon content increases. It also conforms to the assumption that the solid solution consists of the same type of crystal whether it is formed from gamma iron and carbon or from gamma iron and cementite. The A_3 line is located at 761 degrees Cent. in accordance with the work of Scott[11]. The exact location of the point A is not known but if the conclusions of Honda[9] are correct, iron carbide is stable immediately below the solidification temperature. The line AJ was obtained by drawing a smooth curve through the lowest solubility values given by Schwartz[3]. The point A was arbitrarily taken on this line at 1110 degrees Cent. The line AC was drawn to connect A and C and to fall to the right of all values obtained by Schwartz.

It is believed that Fig. 1 will be of great assistance in understanding the graphitizing process of white cast iron.

but the speed of the process is greatly reduced at lower temperatures. In fact, temperatures of 800 degrees Cent. or lower require prohibitively long heating periods to complete the decomposition of massive cementite, while at 1,000 degrees Cent. the action is completed in about 3 hours.

Now, if the specimen is slowly cooled the composition of the solid solution will traverse the line KJ, which means the depositing of excess carbon as the temperature is lowered, until the carbon concentration reaches the value corresponding to J. If the cooling from the temperature of K to that of J is too rapid, a sufficient departure from the saturated value of carbon in solid solution will be produced so that grain boundary, or shell, cementite will be thrown out. Since cementite decomposes very slowly at lower temperatures it is imperative that its formation during this cooling period be avoided. If the cooling has been sufficiently slow, then at the point J simultaneous precipitation of Beta iron and temper carbon should begin.

Such precipitation does occur and this point is therefore the iron-carbon eutectoid, and the products produced represent the condition of stable equilibrium below this temperature. At this temperature it should only be necessary to extract sufficient heat in order to effect complete graphitization.

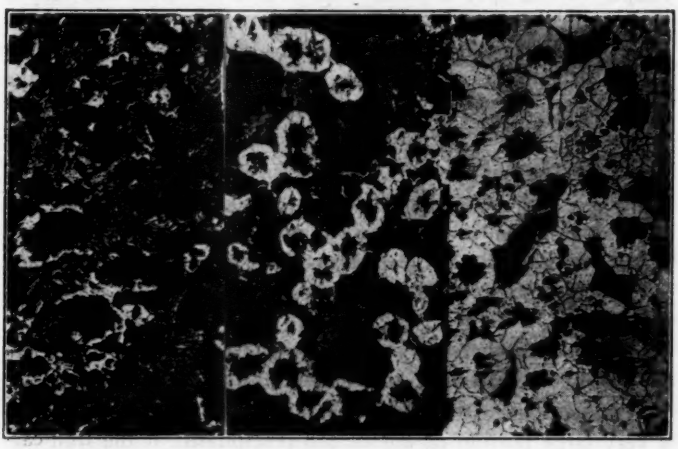
Behavior When Cooling Rates Are Too Rapid

It is conceivable that sufficiently slow under-cooling below the temperature of J would result in extending the line AJ down to, or below, the temperature of A^1, metastable* and the action of graphitization continue as outlined. A number of investigators have reported graphitization continuing at these low temperatures. The potential producing graphitization would be increased by undercooling within proper limits and also continuous deposition of temper carbon would be favored by extensive and intimate contact with temper carbon already present.

The effect of rates of cooling more rapid than those necessary to bring about the actions mentioned in the preceding paragraph is the precipitation of ferrite in excess of that corre-

*The iron-carbon eutectoid will be designated by A_1 stable and the iron-cementite eutectoid by A_1 metastable as has been done by H. A. Schwartz.

sponding to points on an extension of the line AJ and would result in the composition of the solid solution shifting along the line JC, or nearly so, until the point C has been reached at which time precipitation of pearlite occurs. It is common experience that too rapid cooling from these temperature regions results in some pearlite being obtained. During this shift of



2a 2b 2c

FIG. 2—VARIATION OF STRUCTURE WITH RATE OF COOLING; (a) RAPID COOLING; (b) MEDIUM COOLING; (c) SLOW COOLING

composition Beta iron is necessarily deposited in excess of that corresponding to the points on the extension of the line AJ. This shifting from the action of the iron-carbon eutectoid to that of the iron-cementite eutectoid causes the formation of the well-known "bull's-eye" structure, the formation of which will be discussed in more detail immediately.

The examination of furnace cooled specimens of white iron composition shows that until graphitization has progressed to a considerable degree in the critical range, the temper carbon spot is at some point in contact with pearlite. This is shown in Fig. 2a. Immediately before its formation this pearlite must have been solid solution of metastable eutectoid composition. This suggested directly that the growth of the temper carbon

spot was affected by diffusion of carbon through the solid solution to the primary carbon spot formed above the critical range. So long as this contact exists growth of the carbon spot is possible at this point. In specimens of partially malleabilized iron, whose combined carbon content has been reduced to 0.3 per cent or 0.4 per cent by graphitization, the shell of ferrite around the temper carbon spot acquires considerable thickness and only a very small per cent of the carbon spots show the above mentioned contact. It is evident that as graphitization nears completion, islands of solid solution completely separated from the large temper carbon spots result. This is well shown in Figs. 2b and 2c.

The idea that the combined carbon in these islands of solid solution is precipitated on primary carbon spots and also that the graphitization in the critical range takes place below instead of above the Beta-Alpha transition caused Archer[1]* and Schwartz[2] to conclude that carbon must be slightly soluble in ferrite and Honda** to suggest that carbon monoxide and carbon dioxide may act as a carrier of the dissolved carbon through the ferrite to the temper carbon spot.

The evidence to be presented immediately will show that a very large portion of the carbon precipitated at the iron-carbon eutectoid is not precipitated on the carbon spots which existed above the temperature of the iron-carbon eutectoid. It will be shown that the carbon precipitated during the action of the iron-carbon eutectoid is distributed in the form of very small spots throughout the ferrite matrix. If none of the eutectoid carbon is precipitated upon the primary temper carbon spots, the assumptions of Archer and Schwartz, as well as that of Honda, become unnecessary, though the mechanism suggested by the latter may be shown to be feasible if cementite is assumed to be metastable at the temperature of the iron-carbon eutectoid. The reason that the mechanism suggested by Honda does not operate between the solid solution and the primary carbon spots to a much greater extent during precipitation of Beta iron and temper carbon is probably due only to the slowness of the action of these gases through the comparatively

*Small numbers refer to numbered references on page 623.
**Personal correspondence with H. A. Schwartz.

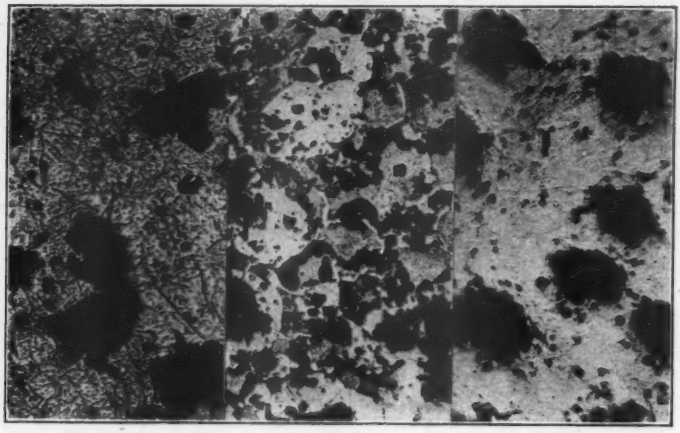
large distances over which carbon would be transported. It is entirely possible that they constitute the carrier over the much smaller distances involved between solid solution and the very small eutectoid carbon spots.

Structural Evidences of an Iron Carbon Eutectoid

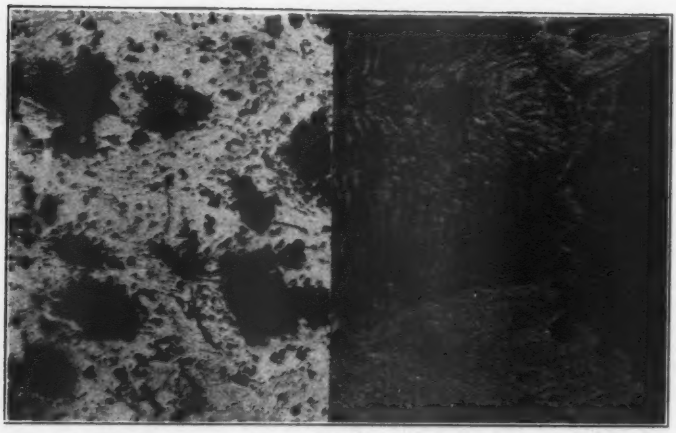
It was noticed that by extremely careful polishing of a sample of malleable iron with rouge there appeared a large number of small carbon spots scattered throughout the ferrite. This suggested a possible structural evidence of the iron-carbon eutectoid action taking place throughout the solid solution and not by a transfer of carbon to the primary carbon spots. By polishing more carefully on a chamois skin kept wet with water, it was discovered that the number of these small carbon spots became striking. It was considered that if these carbon spots were a result of the iron-carbon eutectoid action they should disappear when a sample of malleable iron is heated above the range and reappear as the solid solution graphitizes on slow cooling.

To test this idea, samples of commercial malleable were heated to a temperature of about 885 degrees Cent. for a day. This extended heating was to insure complete saturation of the solid solution. The temperature was then lowered at the rate of 9 degrees Cent. per hour to a temperature of 773 degrees Cent. when a sample was taken out and quenched. The photomicrograph, Fig. 3a, shows a matrix of martensitic structure with a little troostite. The matrix is practically devoid of small carbon spots. At this temperature there had been no action of the iron-carbon eutectoid. Samples taken out before this one showed a similar structure. Another sample quenched at 746 degrees Cent. did not show eutectoid action.

A photomicrograph, Fig. 3b, of a sample quenched just as the temperature 721 degrees Cent. was reached shows the beginning of the eutectoid action in the grain boundaries and around the primary carbon spots. The absence of small carbon spots in the solid solution areas and their presence in the grain boundaries and in the ferrite is very noticeable. The martensitic areas of the solid solution are fringed with troostite, which must not be mistaken for carbon.



3a 3b 3c



3d 3e

FIG. 3—PHOTOMICROGRAPHS SHOWING STRUCTURES DUE TO QUENCHING FROM TEMPERATURES IN THE VICINITY OF THE LOWER CRITICAL RANGE; (a), (b), (c) AND (d), —X 100; SAME AS (b), BUT UNETCHED —X 100; (e X 300

A photomicrograph, Fig. 3d, of a malleable sample quenched at 721 degrees Cent. but one hour later than the last shows the nearly complete graphitization of the piece. In the limited areas of the solid solution the small carbon spots are again absent while they are distinctly numerous in the ferrite areas. In this sample, a few small islands of pearlite were found scattered in the piece. This is shown in Fig. 3e. The absence of pearlite in the sample whose treatment produced the structure shown in 3b, wherein it is evident that the action of the iron-carbon eutectoid has been active for some time, and the presence of pearlite in the sample whose structure is shown in 3d and 3e indicates that iron-carbon eutectoid action was initiated before the precipitation of pearlite began.

A sample quenched at 696 degrees Cent. showed the complete graphitization of the piece. The time from the initiation of the action of the iron-carbon eutectoid to its completion was between 4 and 5 hours.

Examination of samples of partially malleablized iron which have been cooled rather rapidly through the range only once show many small carbon spots in the solid solution areas. See Fig. 4c. These spots are evidently not eutectoid carbon. An examination of Figs. 4a and 4b in this connection indicates that at temperatures just below that of complete solidification there are also many small carbon spots. Many of these undoubtedly persist until the action of the iron-carbon eutectoid begins. Such spots might be found in solid solution areas in partially graphitized material.

When the completely malleablized iron, however, is reheated through the range, say to 885 degrees Cent., and held there for 24 hours, all of the small carbon spots, eutectoid and proeutectoid, are dissolved. When this is again slowly cooled, from temperatures above the critical range, carbon in excess of that necessary for the iron-carbon eutectoid value has an opportunity to diffuse over to the primary temper carbon spots and thus on this second and subsequent heatings followed by slow cooling only the eutectoid carbon spots remain, i. e., the solid solution areas are free from them.

We may consider the formation of the ferrite shell and the eutectoid action to take place as follows: The precipitation

FIG. 4—PHOTOMICROGRAPHS SHOWING INITIATION OF GRAPHITIZATION; a, WHITE IRON TREATED AT 1,000 DEGREES CENT. FOR SHORT PERIODS AND AIR COOLED, UNETCHED X 100; (b) SAME AS (a), X 450; (c) SAME AS (a), BUT FURNACE COOLED, X 100

of the first temper carbon and ferrite at the iron-carbon eutectoid is accompanied by deposition of the carbon on the primary carbon spot and the accompanying ferrite in contact with it. Mahin[3, 4] has shown that both metallic and non-metallic inclusions promote segregation of ferrite to a remarkable extent. In the present case we have the allotropic form of carbon which is undergoing precipitation. We also have the lowest concentration of carbon in the solid solution in the vicinity of the temper carbon spot, since the solubility of carbon from carbon is less than it is from cementite.

The precipitation of the first ferrite about the primary carbon spot is due to two factors: First, the carbon spot promotes the precipitation of carbon and second, it acts as an inclusion to promote the separation of ferrite. Eutectoid action after the ferrite envelope is completed takes place by the deposition of ferrite upon that already in the shell while the carbon is precipitated throughout, forming the small carbon spots. These carbon spots may therefore be considered as evidence of an eutectoid structure. The formation of the ferrite shell around the primary carbon spots, as outlined in the foregoing paragraph, produces the well known "bull's-eye" structure.

Application of the Mechanism for Graphitization to the Malleablizing Process

The mechanism which has been given leads to the belief that complete graphitization could be brought about in much shorter periods than is now used commercially. It also indicated that a whole series of intermediate products of graded physical properties could be produced by only minor variations in the annealing treatment.

Experiments were conducted therefore in an attempt to accomplish these results.

The white iron used in these experiments was of normal composition. Its analysis follows:

Material	Silicon	Sulfur	Phos.	Mn.	T.C.
White cast iron	0.94	0.037	0.166	0.26	2.23

Our previous work showed that it required about 3 hours at 925 to 1,000 degrees Cent. to completely absorb massive cementite. This work also showed that the absorption of this cementite was much slower at the lower temperatures used in the commercial process. It is essential that all massive cementite be absorbed before cooling starts and that the cooling be so regulated that no grain boundary cementite be precipitated as the temperature falls to that of the lower critical. Having eliminated all free cementite for all temperatures above the critical a further condition for the obtaining of complete graphitization is that the rate of cooling through the critical (the iron-carbon eutectoid) be retarded sufficiently to avoid the formation of pearlite. It is well known that in commercial practice this final cooling rate is considered to be 5 or 6 degrees Cent. per hour as a maximum.

With these facts in mind the following treatment was used for shortening the cycle for complete graphitization. Ten standard five-eighth inch tensile test bars were placed on end, unsupported and unpacked, in an L & N Hump furnace whose temperature was at 927 degrees Cent. The temperature dropped to 649 degrees Cent. and it required 40 min. for it to again reach 927 degrees Cent. This temperature was maintained for 3 hours and then it was lowered to 840 degrees Cent. in 1 hour. Then the cooling rate was reduced so that the bars cooled uniformly and slowly to 716 degrees Cent., which required 14 hours (rate 9.5 degrees Cent. per hour). At this time the rate was further reduced to 5.5 degrees Cent. per hour, so that the bars cooled to 649 degrees Cent. in an additional time of 12 hours. The process was considered complete when 649 degrees Cent. was reached, and it will be noted that the complete overall time required was within 31 hours.

It has been shown[5] that the iron-carbon eutectoid for white cast iron lies at 771 degrees Cent. and that it is easily undercooled to about 716 degrees Cent. Therefore in the above experiment the 5.5 degrees Cent. cooling rate was not used until a temperature of 716 degrees Cent. had been reached.

Three of these bars were tested and gave the results which follow:

Tensile Strength Pounds Per Square Inch	Yield Point Pounds Per Square Inch	Elongation Per Cent in 2 Inches
48,000	30,200	14
45,500	30,400	11
48,200	31,900	12

That graphitization is completed is shown by Fig. 5a.

It has not been shown that the above cycle is the shortest one possible. It is believed that an application of the same principles as above outlined will allow a more rapid cooling between 927 and 849 degrees Cent. Also it is almost certain that material can be removed from the furnace at temperatures higher than 649 degrees Cent. without impairing the resulting properties. A one day malleable is well within the possibilities of laboratory demonstration.

Production of Intermediate Products

It is considered desirable at this point to state rather carefully the principles which underlie the control of properties when graphitization is only partially completed. It is known that the effective strength of grain boundary cementite in hypereutectoid steels is very low, probably approximating 5,000 pounds per square inch. Grain boundary cementite when present also tends to sharply and radically reduce the ductility. As long as massive cementite is present in a white iron at annealing temperatures there is always grave danger that grain boundary or shell cementite will form during the subsequent cooling. It is imperative, therefore, that the high temperature be maintained until all massive cementite be absorbed and further the cooling down to the critical must be so regulated as to avoid the formation of shell cementite. This is necessary if materials having tensile properties of any commercial promise are to be obtained.

It is evident from the foregoing that combined carbon in excess of that to form pearlite will result in undesirable physical properties. It is known that in steels of normal structure the strength increases with carbon increase until a structure of one hundred per cent pearlite is attained, at which time it has

reached a value of 125,000 pounds per square inch, and though the ductility decreases with carbon increase a pearlitic steel retains 10 per cent elongation. It would be expected, therefore, that a material of maximum possible strength would be obtained from white cast iron if the graphitization proceeded only until a pearlite matrix resulted, and moderate elongation should still be retained. This material would then consist of pearlite containing about 10 per cent by volume of temper carbon and the resulting properties should approach those of pure pearlite. If the graphitization is carried beyond this point the strength

Table 1

Treatment.	Overall Time, Hours.	Tensile Strength, Pounds Per Square inch.	Yield Point by Dividers, Pounds Per Square Inch.	Elongation, Per Cent in 2 Inches.	Impact Values (Izod), Foot Pounds.	Structure, see Fig. Below.	Remarks.
3 hours at 927 degrees Cent.—Cool to 849 degrees Cent. in 45 minutes—3 hours at 849 degrees Cent.—Cool to 649 degrees Cent.—Cooling rate of 3.6 degrees Cent. per minute.	8	74,400	49,000	4	8		
		67,800	49,000	3½	8	Fig. 5b	
		67,500	43,500	5½	8		
3 hours at 982 degrees Cent.—Cool to 899 degrees Cent. in 45 minutes—3 hours at 899 degrees Cent.—Cool to 649 degrees Cent.—Cooling rate of 2.8 degrees Cent. per minute.	9	69,000	49,500	4½	8		
		67,000	44,500	4½	10	Fig. 5c	
		72,500	47,500	5½	8		
3 hours at 982 degrees Cent.—Cool to 849 degrees Cent. in 1 hour 20 minutes—6½ hours at 849 degrees Cent.—Cool to 649 degrees Cent.—Cooling rate of 2.2 degrees Cent. per minute.	13	69,250	45,000	6	8		
		68,750	45,600	5½	8	Fig. 5d	
		60,380	45,500	6	8		
3 hours at 982 degrees Cent.—Cool to 899 degrees Cent. in 1 hour—3 hours at 899 degrees Cent.—Cool to 649 degrees Cent.—Cooling rate of 1.7 degrees Cent. per minute.	10½	53,500	36,600	9	8		
		56,600	36,100	8½	8	Fig. 5c	
		57,600	38,200	10	8		
For Comparison							
3 hours at 927 degrees Cent.—Cool to 849 degrees Cent. in 1 hour—Cool to 716 degrees Cent.—At rate 9.5 degrees Cent. 1 hour—Cool to 649 degrees Cent.—At rate 5.5 degrees Cent. 1 hour.	31	48,000	30,200	14			
		45,500	30,400	11		Fig. 5a	
		48,200	31,900	12			
Impact test on malleable from same pour annealed with commercial run of work					14 15 18		

Impact tests were run on bars from the same heat, but not on the same bars as used for tensile test run on bars as cast.

should progressively decrease and the ductility should progressively increase until they attain values as found in normal malleable iron. It should be recognized of course that we are here dealing with a cast material which has not been mechanically worked as is the case in steels whose properties are quoted. Matrix structures in treated cast irons might be expected to very nearly duplicate the physical properties of the same structures in cast steels.

In Table 1 are tabulated the properties of products obtained by five treatments. It is to be noted in the accompanying figures that in every case the graphitization was carried to such a point that a hypo-eutectoid matrix resulted. The treatment previous to reaching the eutectoid temperature, though varied, was such as to insure the elimination of any free cementite. The table is arranged in the order of the cooling rates employed in carrying the material through the eutectoid range. It is evident from the figures that as the cooling rate decreases the pearlite in the matrix also decreases until in the case of a 5.5 degrees Cent. per hour cooling rate all combined carbon has been eliminated. Attention is called to the continuous variation in tensile properties and the overall time for their production. Note that in an overall time of 10½ hours a material has been produced which meets the specifications of the American Malleable Iron Association. As the cooling rate in these treatments increased the tensile properties varied from those of malleable iron to values of about 70,000 pounds per square inch strength and 4 per cent elongation. When the treatment is regulated so that the carbon concentration in the solid solution is such that a normal pearlite matrix with very little free ferrite results on cooling through the eutectoid range, the tensile strength values will mount to 80,000 to 85,000 pounds per square inch with 5 to 6 per cent elongation. The first treatment cited in Table 1 shows lower strength than this because graphitization had progressed so far that large amounts of free ferrite had been formed, and the elongation values are also somewhat lower because a cooling rate of 3.6 degrees Cent. per minute is too rapid to allow the formation of truly normal pearlite.

There is a general rule known to hold for all normal iron-carbon alloys that the yield point has a value of about 2/3 of the tensile strength. Any of the products here presented conform very closely to this rule. The yield points obtained are of the same order of magnitude as those found in normal steels of the same combined carbon content. For example, Langenberg[6] gives for a normalized cast steel of 0.3 per cent carbon a value of about 47,000 pounds per square inch, and Stoughton[7] gives a table for worked steels in which the elastic limit of 40,000 pounds per square inch is given for 0.4 per cent combined carbon and 38,000 pounds per square inch for 0.3 per cent combined carbon.

The Izod impact test on these intermediate products of annealing gave results which remained practically constant at 8 foot pounds regardless of the treatment. It is obvious that this value is sharply doubled when complete graphitization has been accomplished. It is of interest to note, however, that this impact value compares very favorably with values for normalized cast steel as given by Langenberg[6]. He gives a Charpy impact value of 11.32 foot pounds for a cast steel of 0.3 per cent carbon. He further gives values for normalized forged steel which show that the impact value decreases rapidly as the combined carbon content increases. For a steel of 0.32 per cent carbon a value of 15.2 foot pounds is given, and for a carbon content of 0.46 per cent the value is 7.99 foot pounds.

It is agreed that a comparison between Charpy and Izod impact values is rather difficult to make. Ordinarily, however, the Charpy values run somewhat higher than Izod values when comparative tests are made. It would seem therefore that these comparisons are legitimate. Reference is made to the work of Dix[8].

There has been occasion for machining these intermediate products both on a lathe and on a milling machine and they presented no difficulty. The surface produced resembles that of machined steel very closely.

It would seem that a cast iron which by a short treatment can be given properties such as reported should find commercial uses. The yield point, that strength characteristic upon which design is based, is as high as that for normal steels of the same

combined carbon content and is superior to that of malleable iron. The shock resistance is comparable to that of steel and though less than that of malleable iron would seem to be ample to allow the slight changes in shape sometimes required in assembling and similar operations. As an example of possible commercial uses consider the ordinary malleable link chain and sprocket wheel. This chain frequently gives difficulty due to stretching and riding the sprockets, and due to wear on both sprocket and link the same difficulty ensues. It is believed that these parts made of the same weight of material with properties such as reported, having about 40 per cent higher yield point and a greater wearing resistance due to the presence of pearlite in the matrix, would largely eliminate the difficulty. These intermedite products seem to offer possibilities of reducing the weight or the cost, or both, of many designs now employing malleable iron or steel.

It is realized fully that the treatments here given differ from those used commercially. Somewhat higher temperatures are used, more rapid temperature changes are involved and the use of packing material is eliminated. These changes are considered necessary in order to realize the short annealing periods obtained in these experiments. Dispensing with a packing material necessitates the substitution of a suitable furnace atmosphere and a study of the effect of atmosphere upon resulting products. This study is in progress. It has already been observed that the elimination of packing material and its accompanying weight seems to have very largely done away with warping.

It is believed that the employment of a suitable atmosphere with a traveling hearth furnace offers possibilities of making these laboratory treatments commercially feasible.

A Study of Some Factors Affecting Carbon Form

Since the shorter annealing times used in these experiments to obtain malleable iron entails the use of temperatures higher than those ordinarily used in present commercial practice, a knowledge of the effect of such high temperatures upon the structures is desirable. It is especially important to obtain temper carbon of good spherical form, because it is known that when

the carbon is deposited in elongated patches, or in any irregular form, both the strength and ductility of the resulting product are appreciably lowered.

We are familiar with the quite common belief that cupola iron and air furnace iron of identical composition will give marked differences in the form of carbon deposited, when annealed in the same pot. The belief is prevalent that under identical conditions cupola iron produces star-shaped deposits of carbon whereas air-furnace iron deposits spherical shaped carbon.

The experiments to be described were conducted on air-furnace iron and, if the above beliefs have any foundation in fact, the conclusions drawn apply to air-furnace iron only. Furthermore, in the investigations here reported air-furnace iron of of a single heat was used. We believe that the observations made will hold for usual air-furnace iron compositions.

With the foregoing limitations in mind a series of experiments were carried out to determine;

(1) the maximum temperatures which would result in good carbon form,

(2) if the rate of heating to temperature affects the carbon form,

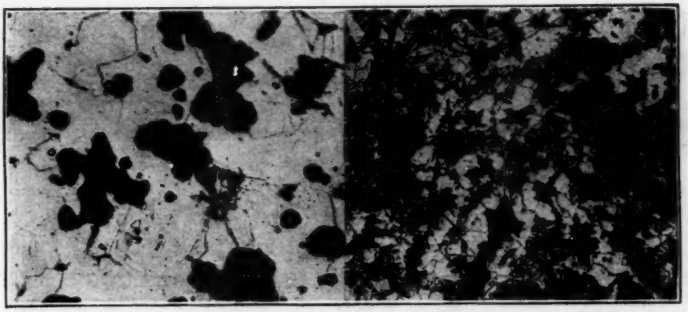
(3) if carbon of poor form can be corrected at temperatures above the critical range,

(4) if the action of the iron carbon eutectoid affects the carbon form and,

(5) if carbon of poor form can be corrected at temperatures below the critical range.

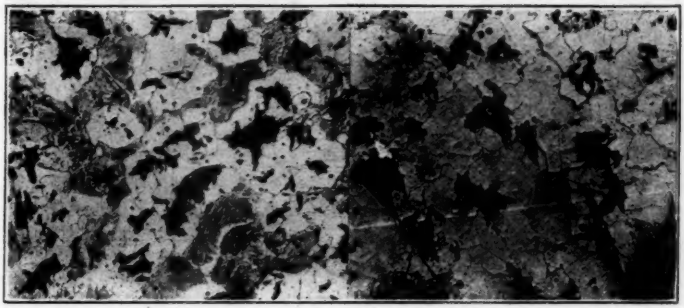
To study factors 1 and 2 the following experiment was performed.

Small samples of white iron were placed in a furnace when at 705 degrees Cent.; a temperature lower than that of the iron-carbon eutectoid. Their temperature was raised with the furnace so that 3 hours were required to reach the high temperature. At this time additional samples were introduced into the furnace. These samples attained furnace temperature, as noted by the time required to attain furnace color, in approximately 7 minutes. All samples were held at temperature for an additional time of 1 hour. They were then removed from the fur-



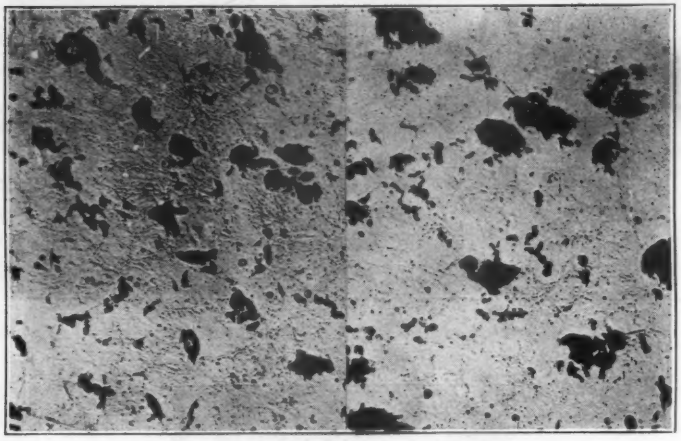
5a 5b

5c



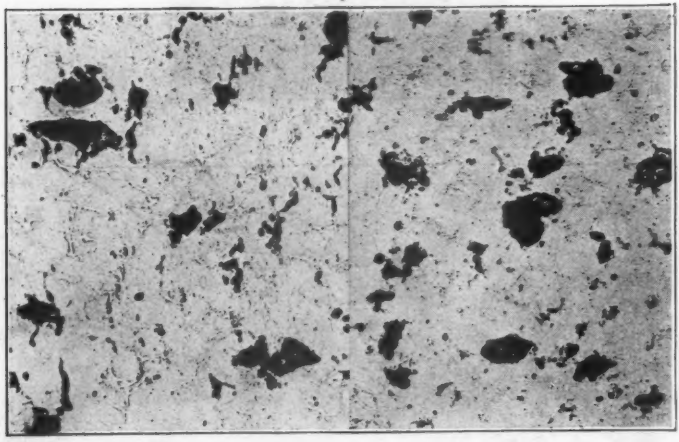
5e 5d

FIG. 5—SHOWING STRUCTURES OBTAINED BY TREATMENTS LISTED IN TABLE 1, — X 100



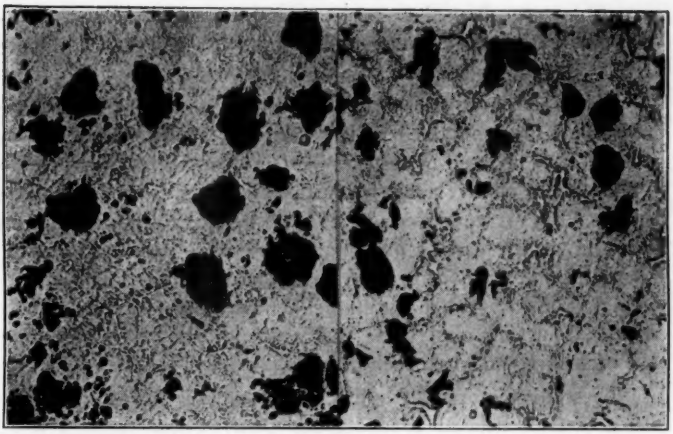
6a 6b

FIG. 6—SHOWING THE FORM OF CARBON SPOT OBTAINED AT 1038 DEGREES CENT., UNETCHED, X 100; (a) BROUGHT FROM ROOM TEMPERATURE IN APPROXIMATELY 7 MINUTES; (b) BROUGHT FROM 705 DEGREES CENT. IN 3 HOURS



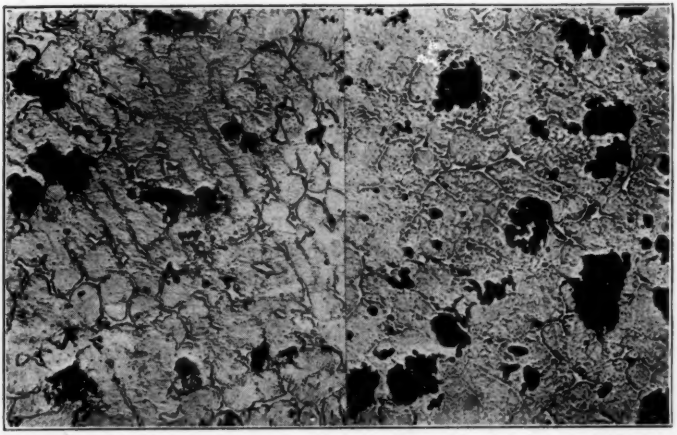
7a 7b

FIG. 7—SHOWING FORM OF CARBON SPOT OBTAINED AT 982 DEGREES CENT., UNETCHED X 100; (a) BROUGHT FROM ROOM TEMPERATURE IN APPROXIMATELY 7 MINUTES; (b) BROUGHT FROM 705 DEGREES CENT. IN 3 HOURS



8a 8b

FIG. 8—FORM OF CARBON SPOT OBTAINED AT 954 DEGREES CENT., UNETCHED X 100; (a) BROUGHT FROM ROOM TEMPERATURE IN APPROXIMATELY 7 MINUTES; (b) BROUGHT FROM 705 DEGREES CENT. IN 3 HOURS



9a 9b

FIG. 9—FORM OF CARBON SPOT OBTAINED AT 927 DEGREES CENT., UNETCHED X 100; (a) BROUGHT FROM ROOM TEMPERATURE IN APPROXIMATELY 7 MINUTES; (b) BROUGHT FROM 705 DEGREES CENT. IN 3 HOURS

nace and were allowed to cool to room temperature in the air. High temperatures of 1038, 982, 954, and 927 degrees Cent. were used.

Photomicrographs showing typical appearances of the temper carbon form obtained in this series of specimens are given in Figs. 6, 7, 8, and 9 respectively. A consideration of these figures shows that if a temperature not higher than 927 or 954 degrees Cent. is employed there is no appreciable difference in the form of the carbon deposit at these very different heating rates, and the form compares favorably with that of the commercial product. When the higher temperatures of 982 or 1038 degrees Cent. are used there is a tendency for the more rapid rate of heating to give a slightly poorer form.

To study factors 3, 4 and 5, small samples were introduced into a furnace held at 1038 degrees Cent. These samples were placed in the furnace at intervals, so that its temperature dropped only slightly at each introduction. Enough time was allowed between each addition to the charge for the temperature to return to 1038 degrees Cent. Using this method of charging, the samples came to temperature in approximately 7 minutes. This method of charging was employed because a rather poor form of carbon in all samples was desired in order that improvement in form due to subseqeunt treatment might be more accurately judged. A few samples for examination were successively removed at the end of each of the following heating periods.

(a) after 1 hour at 1038 degrees Cent.

(b) after a rapid drop in temperature to 982 degrees Cent. and an additional heating of 18 hours at this temperature.

(c) after a further drop in temperature to 849 degrees Cent. in 1½ hours, and 48 hours of heating at this temperature.

(d) after an additional heating of 48 hours at 849 degrees Cent.

(e) after a slow cool from 849 to 732 degrees Cent. at a rate of 6 degrees Cent. per hour.

(f) after an additional heating of 24 hours at 732 degrees Cent.

(g) after lowering the temperature from 732 to 649 degrees Cent. at the rate of 6 degrees Cent. per hour.

(h) after further heating periods of 12 hours, 36 hours and 60 hours at a temperature of 649 degrees Cent.

With the exception of a slight increase in the quantity of carbon as graphitization proceeded, there was no appreciable change in the form of the carbon spots throughout this procedure.

This series of experiments leads to the conclusion that if carbon is once deposited in poor form, subsequent treatment will prove of no appreciable value in correcting it. It is imperative, therefore, that the initial heating of the white iron be so conducted that the initial deposition of carbon be in good form. It has been shown that this can be accomplished, if the temperatures employed are not higher than 954 degrees Cent., regardless of the rate of heating. If reasonable heating rates, such as are possible commercially, are used, temperatures even higher than this can be used without causing the initial carbon deposition to be of poor form.

This indicates that the short annealing periods outlined in this paper are feasible in so far as satisfactory form of carbon in the final product is concerned.

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Discussion

The Mechanism of Graphitization of White Cast Iron and Its Application to the Malleablizing Process

By H. A. Schwartz, Cleveland, Ohio

The paper by Dr. Hayes and his associates is to be regarded as a significant contribution to our knowledge of theoretical metallurgy. It is certainly worthy of serious study and discussion by those interested in the problems, for it is only by such discussions that the strength or weakness of conclusions can be ascertained on subjects where differences of opinions may exist.

The first point of interest is the definite reference made to beta iron as such. Avoiding any dispute as to the existence or non-existence of beta iron as a distinct allotropic phase, we must deal with the fact of the crystallographic identity and magnetic difference of iron above and below A_2.

There exists in the literature a single reference: Baraduc-Muller *Revue de Metallurgie*, 1910, Vol. II, page 728, known to the writer in abstract only, which touches on the possible sigficance of a distinction between alpha and beta iron in this connection. This reference alleges that graphite is deposited in those iron silicon carbon alloys in which A_2 coincides (by inference is lower than) A_1.

The present writer is tentatively of the opinion that absolutely pure hypo-eutectic iron carbon alloys may be incapable of complete, or perhaps of any graphitization. In such alloys A_2 is above A_1. In the commercial cast iron it has been shown by Hayes and his associates, and confirmed by others, that the known thermal critical point curves show A_2 below A_1. These facts agree with the Baraduc-Muller thesis. An exact check may be difficult, involving very precise magnetometric investigations of considerable difficulty. To the present writer it seems likely that the silicon content at which A_1 passes A_2 is possibly too high to correspond to a distinct change in graphitizability, although this is but a conjecture.

Much iron has been annealed in the past with silicon under .50. See for example, Moldenke's "The Production of Malleable Castings," page 72.

It would be interesting to have a further exposition from Dr. Hayes' laboratory of his views on the significance of the distinction between alpha and beta iron.

Fig. 1 of the paper under discussion involves three points upon which there may not be unanimity of opinion. The diagram of Hayes, Diederichs, and Flanders is based on the acceptance of the Honda suggestion, that cementite is the stable phase below the solidus, and not a result of supercooling. On the other hand, Ruer ("Zeitschrift fur anorganische und allgemeine Chemie," 117-4) reports the temperature of the solidus in the stable system at 1152 degrees Cent. and of the metastable at 1145 degrees Cent. This will imply that the survival of Fe_3C in white cast iron is due to supercooling, and not to its being the stable phase. Jeffries and Archer ("Science of Metals") show a double diagram which accepts this viewpoint in principle.

The present writer regards the Ruer data as more probable than the Honda data on a *priori* grounds, and also because he has experimental evidence of the conversion of cementite into graphite at a temperature so near the melting point that the metal was incapable of holding its own shape against gravitation and surface tension. He would agree with Honda, however, that, at least in the hypoeutectic alloys primary graphite never crystallizes from the liquid phase, graphite being always a decomposition product of cementite.

The location of the eutectoid point (C, Fig. 1) for the metastable system is admittedly an approximation. It may be submitted that a better aprroximation could be had by considering the known effects of silicon on the A_1 and A_3 metastable points. The writer is informed (private communication) that silicon has been found to raise A_3 metastable about 100 degrees Cent. for 1 per cent silicon. The matter was checked up in the writer's laboratory by Campbell and Johnston ("Effect of Silicon on the A_3 Point of Steel," thesis presented to Case School of Applied Science), who obtained values approximating 95 degrees Cent. per 1 per cent silicon.

The effect of Si on A_1 has been dealt with by Scott (Transactions of the American Institute of Mining and Metallurgical Engineers, 1922, Vol. LXVII, page 453, and elsewhere) and also by Meacham, working under the writer's instructions (Transactions of the American Society for Steel Treating, 1923, Vol. IV, page 635).

The eutectoid composition for a given silicon content could well be determined as the abscissa of the intersection of A_1 and A_3 in the iron carbon diagram, corrected for the effect of Si. on these lines. Irrespective of the question whether this yields a figure materially different from that of the author's, the writer feels the suggestion to be sounder in principle as not using the A_3 of silicon free alloys, which has no necessary connection with the matter.

It has been shown in this laboratory ("Effect of Silicon on Equilibrium Diagram of System Carbon-iron near Eutectoid Points," Transactions of the American Institute of Mining and Metallurgical Engineers, 1923, Vol. LXIX, page 791) that A_3 in the stable system is lower than A_3 metastable, for the same silicon content by an amount increasing with the silicon. The direction of A_3 stable can at most, be inferred, but its end at the eutectoid can be located.

The A_3 line drawn by the authors can not be reconciled to these facts, and will require radical modification unless the writer's conclusions be shown to rest upon an incorrect experimental foundation. Inasmuch as the publication referred to presents evidence that the alpha, gamma (possibly beta, gamma) transformation in a ternary alloy of given composition is different in the stable and metastable systems, it casts a doubt upon the validity of the assumption "that the solid solution consists of the same type of crystal whether it is formed from gamma iron and carbon and gamma iron and cementite." This assumption can only be made by showing cause for rejecting the data and conclusions referred to. It may be said, however, that the difference between A_3 stable and A_3 metastable is not inconsistent with the author's image of what occurs during cooling. According to the Fig. 1, a metal slowly cooled along *AJ* reaches *J* as a saturated solid solution containing graphite. Thereafter it can

graphitize by depositing a eutectoid or, if further cooling be somewhat rapid, its composition may shift along *JC*, depositing body centered iron (alpha or beta) and metastable solid solution, the latter being finally converted to pearlite at *C*.

Now, according to our data (loc. cit.), if the line from 900 degrees Cent. to *J* be taken as A_3 stable, A_3 metastable will be higher going through *C*, and for example, to 1000 degrees Cent. and intersecting *A J* at another point, J^1. Then our previous discussion still holds, except that the composition on reaching J^1 may continue in the metastable system to *J*, and deposit the eutectoid, or on passing J^1 may shift somewhat along J^1 *C*, and go over, more or less, to the metastable system and finally to pearlite and ferrite. As a matter of fact, the structural entities resulting from either assumption are the same, and acceptance of our facts do not seem to necessitate any essential change in the application made by the authors.

The report of a stable eutectoid is interesting, perhaps the most interesting statement in the paper. The writer can confirm the existence of very finely divided "temper carbon" in malleable cast iron. This has been observed in practice for many years. It has also been considered whether a eutectoid in the stable system might not have carbon nodules approaching the submicroscopic in size. Especially in view of the observation that these fine spots disappear and reappear on heating, and cooling through A_1, as is so ingeniously shown by the authors, a strong presumption seems raised that this is the true eutectoid. The conclusion would be strengthened if it could be demonstrated by what mechanism the holes close up, which would be left when the carbon dissolves in the iron. The density of the solid solution is probably greater than that of the mechanical mixture of carbon and iron, as evidenced by the expansion attending all graphitization. How, therefore, can the metal above A_1 sufficiently expand to completely fill the space occupied by carbon? We must remember also, that the alpha gamma change, *per se*, involves a contraction.

Be it understood that the present writer is not now denying the closing up of these voids, but asking light upon the mechanism by which it may take place. Studies are now in progress

in our laboratory dealing with the density of the material as a whole, and of the matrix alone, and upon dimensional changes on heating and cooling, and it is believed that these studies may have a direct bearing on the matter.

The observations noted by Hayes are, however, not sufficient to demonstrate that carbon can not migrate to a considerable extent in ferrite, and hence, do not necessarily dispose of the belief of Archer and the writer, that the ferrite of the stable system contains carbon in solution in some form, and degree, of concentration. It is quite possible to grow temper carbon nodules of normal and even large size in hard iron at temperatures well below A_1, where neither system should contain anything but ferrite and either cementite or carbon. Whether or not carbon is here precipitated in part as eutectoid, there must have been much migration to grow the large nodules. Indeed, even the finest of visible eutectoid particles require migration to explain them for, if the carbon were deposited absolutely, in situ, an atomic dispersion in the final product would be required.

Consideration has at times been given by the writer to the viewpoint that the iron carbon eutectoid might involve invisibly small masses and so be undestinguishable from ferrite. Honda ("Carbon and Strain Effects on the Specific Heat of Carbon Steels," Science Reports of the Tohoku Imperial University, Series I, Vol. XII, No. 4, page 353), discusses a case where the graphitization of cementite resulted in the formation of free carbon in so fine a state of subdivision as to escape detection. An interesting corollary is, what may be the effect of such a condition on the analytical accuracy of any work involving graphite determinations?

The authors have also wisely seen fit to investigate the relation between geometric form of carbon and temperature. A reference should here be made to the work of Fisher (Transactions of American Foundrymen's Association, Vol. XXX, page 395), who dealt with the same subject.

It is shown by Hayes that 950 degrees Cent. is the upper limit beyond which graphite grows flakier than consistent with modern practice. Subject to the limitation that the form of graphite is probably also dependent upon other variables, not-

ably silicon content, original microstructure of hard iron, etc., the conclusion seems in line with current practice. The effect of heating rate is well brought out and focuses attention upon a point likely to escape notice.

Are we not here justified in the belief that the form of carbon is determined when the nuclei first begin to grow and that with the slower heating growth began at a lower temperature? The writer has evidence that, under laboratory conditions, it is possible to cause "star shaped" graphite to become more nearly spherical and would be inclined to believe that this may, to some degree, occur in practice with appropriately long time, in cooling.

No discussion can be complete without reference to the practical applications proposed by its authors. These proposals are twofold, dealing with the production of normal malleable in decreased time and with the production of other "intermediate" products. All will agree that an increase of temperature rapidly decreases the time to attain stable equilibrium. The upper temperature limits are set by graphite form, tendency to intergranular brittleness, distortion of castings under their own weight, permanence of containers in service, fusibility of packing, if used.

The present authors set a temperature between 950 degrees Cent. and 982 degrees Cent. as that at which the carbon form deteriorates. This is a temperature somewhat under 1800 degrees Fahr., and is not far from the maximum used in commercial practice. There is evidence that at such temperatures the iron, unless handled very carefully in subsequent cooling, develops a tendency to intergranular fracture, and very poor impact result. The cooling rates to just under A_1 are in practice, determined by engineering conditions and not by metallurgical. In no present form of equipment can a large mass of castings be quickly and accurately cooled. Heating times are determined by similar conditions. Packing is already abandoned on much tonnage, and by many plants, both with pots and in tunnel and muffle furnaces.

The suggestions that annealing time can be reduced by decreasing the time to heat up, increasing the maximum tem-

perature and not needlessly prolonging the cooling rates, are all perfectly sound. Many of us have struggled to improve operating conditions in this direction, others may be ignoring their importance. No great further improvements in the application of these principles are possible with equipment of the best character available at the present time. In the use of tunnel kilns, these features have been developed to the uttermost, in some cases possibly overdone, at least temporarily. That a further reduction in heating and cooling times could be made by treating the material in very small lots is equally true and understand. The objection is merely the item of cost. The suggestions of the authors that a continuous type furnace, with a controlled atmosphere, be designed, in which large tonnages, presumably subdivided into small lots, and divested of pots, be treated, is entirely logical, but the apparatus does not exist.

The required pot atmosphere is easily determined. H. R. Payne, under the writer's supervision, has shown that the equilibria of the system CO-CO_2 with austenite, of even low carbon concentration, are so nearly like those with cementite, that, if existent, the differences may be disregarded for present purposes. They may be obtained by consulting Fig. 102 of "American Malleable Cast Iron" by the present writer, and are those compositions lying above the Fe-FeO equilibrium, and below the Fe-Fe_3C equilibrium. This field has been by no means ignored, either by designing engineers or manufacturers, but the problem is not yet even partially solved. Supposedly an electric heat source is indicated, but how air infiltration is to be prevented in a structure such as here considered, especially with provision for a continuous ingress and egress of castings remains for solution.

The quality of material produced by the authors from hard iron annealed to completion is inferior to that resulting in commercial practice from the identical product, and inferior to current specifications. This observation checks many similar ones made in the writer's laboratory, and seems to indicate that the rapid precipitation of carbon is per se detrimental to quality at least in our present knowledge.

This much for the consideration of those users of malleable

who may erroneously expect an immediate and revolutionary decrease of delivery time by the introduction into practice of the author's suggestions, admittedly well founded though they be.

As to the value of the "intermediate" products it may be said that this depends upon whether or not an industrial need exists for articles having these properties. They are certainly not interchangeable with malleable.

Material Fig. 5 *C* is approximately of the tensile properties defined by the standard specifications for malleable castings (the required elongation of 10 per cent is reached in one case of three only). It is, however, very deficient in shock resistance, a property not defined by specification, but actually the most important attribute of malleable cast iron. Whether there is any demand for a somewhat brittle material having the tensil strength of malleable, or a little more, and much less elongation than that product, as now made, coupled with one-half or two-thirds the shock resistance, is a question which only the users of ferrous materials can decide.

A somewhat extended experience with link chain leads the writer to doubt its utility in that field. All chains are subject to jerks (impact) and a rigid material is only useful when its energy of rupture is high. The disadvantage of a chain stretching out of pitch is great, but not so great as that of its snapping in two. The problem has received the attention of those most interested, and conveyor and similar chains are advisedly made of a ductile material in the absence of a sufficiently resilient rigid metal.

The machineability of pearlite materials has already been a subject of friendly controversy with Dr. Hayes, elsewhere. As a restatement of the writer's viewpoint, it may be said that we have been able to learn of no circumstances where a pearlitic material can be machined with tools set-ups designed for that purpose, as readily as can malleable cast iron with the proper set-up for that material. In this opinion we are supported not only by laboratory experiment ("The Significance of Tool Temperatures as a Function of the Cutting Resistance of Metals," The Proceedings of the American Society for Test-

ing Materials, 1923, Vol. 23, Part II, page 27) but by so unanimous an opinion on the part of those doing producing machine work that the present writer is surprised that the fact should be questioned. The pearlitic materials can, of course, be machined on a production basis, but much less rapidly than is true of malleable cast iron. Indeed, many users of high carbon steels are careful to have the carbon present as "spheroidized" cementite rather than pearlite, to make machining at high speeds practicable.

Discussion—Mechanism of Graphitization of White Cast Iron

DR. A. ST. JOHN: I would like to inquire of Dr. Hayes and Dr. Schwartz whether, in their opinion, any valuable information concerning the character and distribution of the carbon and other constituents could be obtained by the method of X-ray analysis in an investigation of this kind? I may say that in support of a belief that might be valuable, that if the carbon is dispersed, as has been suggested, in such a fine degree of dispersion, that you cannot catch it in a filter, that the character of the X-ray pattern would be decidedly different from that of carbon which could be caught on a filter. In other words, we can with the X-ray crystalometer determine, with a reasonable degree of certainty, particularly the sizes that go down to the region of colloidal dimensions. I have, with respect to certain carbon materials, established a schedule of dimensions where the first pattern corresponds to particles that are certainly smaller than 50 atoms in diameter. Now, a carbon atom must be less than a hundred millionth of a centimeter in diameter, and if you get 50 of those you still have an exceedingly small unit, far beyond the resolving power of the most powerful microscope we have. They are colloidal particles and the character of the pattern thus obtained is vastly different from the character obtained from the particles that are visible as distinct spots, at, say, 100 degrees magnification. I would be very much interested to see if the X-rays could not be of service in clearing up some of these problems in the field of malleable cast iron, as they have been of assistance in clearing up some of the problems in more or less worked metals. As far as I know, there has been no attention paid to X-ray analysis of castings, cast material, other than a very small amount of work that I have done myself on special high tungsten cast material. In that particular case I find that the castings procedure has a great deal to do with the entire subsequent history of the material, so much so that I am almost prone to go on record with the belief that the casting procedure and the

properties that are imposed at the time the material solidifies and cools down cannot be removed without some sort of mechanical working; that your heat treatment may carry you through certain conditions back and forth, but the major effects that have been imposed at the time the material was cast are going to last, no matter what you do in the way of heat treatment.

A. HAYES: I might say that I have been wishing very much to take up X-ray analysis studies of the structure of cast iron, but we have just made an expenditure for getting an Ajax induction furnace to make our pure alloys with recently, and it will be some time before I will have face to ask for the expensive equipment required to do that type of work.

It seems to me that there would be a possibility of analyzing the situation satisfactorily by that means. In regard to Mr. Schwartz's short discussion of the possibilities of the migration of carbon through beta iron or alpha iron, as the case may be, I might say that we have run cooling rates as low as some 2 degrees Fahr. per hour, through the critical range, and still got the fine specks that we have interpreted as being an evidence of iron carbon eutectoid action. Of course, that is not saying that if the temperature is held for long periods of time right in that region, that migration at such rates as would ultimately allow considerable growth in those particles might not take place.

In connection with the relative stability of the carbon iron system and the cementite iron system in the vicinity of the lower critical range in pure carbon alloys, I might say that we have just completed a piece of work which is not yet published. It was work done by Mr. Maxwell as a thesis, in which we measured the equilibrium values for carbon monoxide and carbon dioxide in contact with carbon on the one hand and with cementite and ferrite on the other, at the temperatures 650 degrees Cent. and 700 degrees Cent. From those values we calculated the heat of formation of cementite and got a value of minus 18,000 calories, which agrees fairly well with a calorimetric value reported by Ruff recently. We calculated the equilibrium constants for the reaction that would take place between carbon and these gases, on the one hand, and ferrite, cementite, and these gases on the other hand in this range. We found that the equilibrium constant as expressed by the pressure square of CO over the pressure of CO_2, which means, interpreted in terms of composition, that the composition in carbon monoxide of the gases in equilibrium with cementite and ferrite at those temperatures, is higher than the composition of the gases in CO in contact with and in equilibrium with carbon. This, of course, means that in the pure iron carbon system that cementite is metastable at the temperature of 700 degrees. Now, our Mr. Evans is in the midst of his thesis work and he is going to resort to every scheme that can be thought of to get graphitization of pure iron carbon alloys. We have several alloys made, but have not yet completed the experimental work.

In connection with the location of the A_{2-3} line, I may say that we

took the carbon content of pearlite = 0.65 per cent from your curve, Mr. Schwartz. We took our value = 758 degrees Cent. from thermal analysis data, as locating A_1 metastable. Again we took 0.57 per cent carbon as determined in your laboratory, and 771 degrees Cent. determined by us as locating A_1 stable. Drawing a straight line from 758 degrees Cent. and 0.65 per cent carbon through 771 degrees Cent. and 0.57 per cent carbon, the line strikes the zero carbon line at a temperature very near 900 degrees. That was the experimental basis for our putting in the A_{2-3} line. Of course, I realize that we are treading on dangerous ground when we are treating a three component system on a two compotent diagram, but we are doing it on the assumption that we might take a cross section of the iron carbon diagram with some safety.

H. A. SCHWARTZ: May I answer the question of Dr. St. John? We are not experts in X-ray crystallography, but we have had a little occasion to work in that field with Mr. Bain, formerly of the National Lamp Works, and since then with the Union Carbide Company. So far I do not think there is anything that has been done which is of such a character as to justify talking about. The work is very largely preliminary rather than in such a condition that conclusions could be drawn. The first thought that we had was that we might be able to find some difference between the stable and the metastable solid solutions, and we did not see any means of doing so. We tried one scheme for keeping gamma iron solution. We thought a stable system might be made by adding nickel and keeping gamma iron metastable by manganese, but nothing happened; we got the normal result for iron in the one case and for nickel in the other. It was not exactly of that type, but within the possibility of Mr. Bain's determination, and carbon was non-existent in the solid solution so far as the X-ray spectrometric work was concerned. Of course, that carbon might have been stuck in the middle of the lattice and not touched enough so that we were able to get data on the point. We tried the same thing on some quenched material, and while we were able to keep some of the evidences of gamma iron along with the alpha iron, we got nowhere in particular on that, because there was no evidence present of carbon. We had the alpha and the gamma iron and nothing except some cementites besides, so that was fruitless. Very recently we have been trying to locate the silicon atoms, and within the past few days we have come to the conclusion that the silicon atoms based on density conditions were very definitely replacing iron atoms, and not inside of the alpha iron structure. We came to pretty good agreement on that. This should not be taken as a public announcement of a great discovery, but that merely, as far as that has gone, we hope perhaps to get some good generalizations on the position of silicon in those combinations, but that is a large field and not Mr. Bain's principal business

nor mine, and it may be some time before we get anywhere. We have at present some certain silicon cementites which Mr. Bain will probably compare with other cementites. We have always felt that the spectrometer was a good thing.

E. Touceda: I think I might say that no one has been more interested in the mechanism of graphitization than the speaker, who has tried to keep in touch with all that has been done in this direction, but he thinks it quite essential and one of the most important things in connection with this work to consider the effect of oven atmosphere; such atmospheres as obtain in the practical work of the manufacture of malleable iron. It has been found that in the case of an atmosphere of hydrogen only it is very difficult to bring about complete graphitization and that certain reducing atmospheres appear to exert the same influence to a lesser extent. We know that when you take parts of the same sample and anneal them in different annealing ovens different results can be obtained, which can be attributed only to the influence of oven atmosphere, so that oven atmosphere becomes one phase in the system that cannot be overlooked.

Now, leaving this question aside for a moment, it might be of interest to the members to know of some of the experiments we carried out in a practical way in an effort to settle some of these mooted points. About six or seven years ago I designed a little apparatus, with the end in view of watching the changes that take place while a white iron is passing through its critical range, and while it is being held about 100 deg. F. above it. The apparatus consisted of a small water-jacketed brass cylinder closed at both ends. Passing through a stuffing box on the lower end of the cylinder was a small plunger, on top of which was located an electrical resistance unit capable of heating a thin specimen to about 1,600 deg. F., the plunger serving to bring the specimen into focus when the cylinder was in position under the microscope, and vision being possible through a glass window in the head of the cylinder. Great difficulty was experienced in an effort to overcome the development of a very thin film that always would form on the surface of the polished disc as it approached the temperature of the critical range, which in spite of the many trials seemed constantly to form. This film operated to mask any change in structure that might be taking place. Inasmuch as we had obtained a very perfect vacuum it was my thought that the film was caused by occluded gases in the disc. Samples of hard iron were then made in a vacuum furnace in the thought that when the white iron was prepared in this manner this trouble would be overcome. In the thought also that my apparatus was not sufficiently perfect, further experiments were conducted through the courtesy of the General Electric Co. in their research laboratory at Schenectady. Only after great effort and many trials were we able to

overcome the development of this film, during which experiments many peculiar things were noticed. We finally succeeded in avoiding this film in the case of steel and to watch the changes taking place from ferrite-pearlite to solid solution. With this encouragement the apparatus was rigged up in such a manner that a micrograph could be taken every fifteen minutes that would serve to show the progressive changes that were taking place in the hard iron while passing through the range and while subsequently being held at the ordinary temperature of anneal. In the case of white iron, once the disc had passed through the critical range, the structure remained the same irrespective of how long it was held at temperature. In order to ascertain what had happened the disc was removed; the surface reground and prepared, when it was discovered that the surface had been deeply decarbonized thus masking the changes that had taken place under it. The hard iron contained 2.35 per cent carbon and after the piece had been held at the annealing temperature some fifteen hours it was found to have been converted wholly into a steel containing about .25 per cent carbon. Just the exact mechanism by which the carbon disappears the speaker does not know. We were greatly disappointed as we had hoped that several mooted points could be settled through these experiments.

H. A. SCHWARTZ: We happen to have had the same experience Mr. Touceda mentioned. We went through the whole procedure very nicely, and when we got all through we could not understand what we had because it looked like ferrite, and turned out to be ferrite, and there was absolutely no carbon in it. Dr. Rosenhain was in this country a month or so after that and he visited us and I recited that to him as an illustration of what we tried to do, and he said, "Of course, you can distill carbon anatomically from either a molten iron or a solid solution at high temperatures." I merely repeat his view here.

E. TOUCEDA: We could have anticipated that if the temperatures had been high.

H. A. SCHWARTZ: Dr. Rosenhain said it happens below the critical point. He said that at the National Physical Laboratory somebody had come to the conclusion that a low carbon distills more carbon than a high, but it was accounted for by the displacement of the A_3 points.

E. TOUCEDA: Would you think that in the annealing so much of the carbon would have disappeared:

H. A. SCHWARTZ: Dr. Rosenhain thought it would if you worked in a vacuum.

E. TOUCEDA: I think that is what happens; there is no other explanation.

W. R. BEAN: I have done something along that line myself, but I do not feel competent to discuss the subject presented by Dr. Hayes this morning, in particular, but there are a few points I would like to go through hurriedly. First, in the matter of the practical application. I think I could dispose of that side of the question by saying that Mr. Schwartz has said what I would say, in very large part at least; but on page 605 of the paper it states that micrograph 2C represents slow cooling. Now I think, for the sake of accuracy, perhaps it might be stated that it represents slower cooling, because this paper goes into the hands of many individuals and the structure there shown is not a normal malleable structure, such as we get in practice from slow cooling; that is, slow cooling which is necessary to produce a merchantable product in malleable iron. I think that perhaps in the East we come up against machinability to a greater extent than in any other part of the country, and we could not sell a material which was of the structure shown by this particular micrograph. It would go into work to be machined, but for work to be threaded or milled it would not pass; in fact, material which is shown in 3C, page 608, containing very small particles of cementite, would not pass as a merchantable malleable iron to be machined. I am not sure that that is presented as a normal product, as a completely malleableized product.

A. HAYES: May I say that neither of these photographs is presented to show complete malleabilization; they are presented simply to bring out the process and illustrate the mechanism. The first one you mentioned was of a series prepared purposely to bring out the fact that we do get complete isolation of pearlite patches, and nothing else; it was not intended to produce what we would call completely malleableized material; none of the figures on page 608 were for any other purpose except to establish the nature of the eutectoid action.

W. R. BEAN: My point in connection with the first was that some people will misunderstand it if that goes through as representing slow cooling.

A. HAYES: I think your suggestion is a good one, and the table should be changed to prevent a misunderstanding.

W. R. BEAN: I wanted to get that clear in my mind. Now, the question of 31 hour malleable, as to the results obtained, the figures given at the top of page 613, a composition such as was used in this test should average approximately 55,000 pounds tensile strength, 35,500 pounds yield point and 20 per cent elongation in the practice as followed by the majority of malleable foundries today. That is what we would expect and what we would say was a normal result. The figures are, in elongation, above the malleable specification, but the malleable specifica-

tion does not represent the average accomplishment or the normal accomplishment for a material of that composition.

A. HAYES: I might remark that the material that was used in this anneal was one that showed considerably lower tensile properties; that is, we had test bars run through the commercial anneal from this same pour which we used in this experiment, and the test bar in this particular pour ran considerably lower in tensile properties and elongation than some of the other experiments that we ran, but I also want to point out that this represents only a few experiments and we have not yet had an opportunity to investigate intensively this particular field to see what improvement in the product of these rapid methods might be brought about. I might say, that it might be hoped that an intensive study, something of the nature that the Malleable Castings Association has made in this regard, might bring about some further improvement in this material that we have made by hurried methods. I do not think this represents at all the best properties that can be obtained, though they are all we have obtained at this time.

W. R. BEAN: All of us who have worked in malleable iron to any extent have endeavored to shorten the time of annealing, and we have been able to obtain results which can be compared with your results, but we run up against the engineering problem, as Mr. Schwartz pointed out, the inability to provide equipment which will heat the masses that have to be heated, and as was mentioned in the correspondence with you, the question of what you can save over present cost is quite a question. We have been studying somewhat the cost of a simple hardening process, of heating materials for hardening, and the cost runs into the neighborhood of the present cost of the regular malleable annealing process, because of the higher investment, the higher fixed charge that comes with the more elaborate equipment. In the malleable foundry we have simple equipment, equipment that is not complicated, does not require a large investment, and that makes a big difference in trying to work out a problem of this kind from a practical standpoint. In machining, malleable iron is more readily machined than any other ferrous metal commercially produced at the present time. That is one of the main factors which keeps it in the automobile business to the extent that it is there today. It possesses the required strength and the required shock resisting properties, but also it possesses the ability, when there is no pearlite present in the exterior surfaces, to be machined at a higher rate and at a lower cost than any other ferrous metal that has been put into industry at the present time.

Authors' Reply to Discussion—The Mechanism of Graphitization of White Cast Iron

By A. Hayes and W. J. Diederichs

Because the discussion of the paper was cut short on account of time at the convention session, we wish to have the following included. This seems advisable both because wrong inferences seem to have been made from statements which were in the paper and because others may arise from some of the discussion which was given.

The first point which we wish to take up is that of facts in regard to the pure iron carbon system which are still unsettled.

The existence or nonexistence of beta iron is a much debated question. While its crystal structure indicates it to be the same as that of alpha iron yet it is certain that the so-called beta and alpha irons have different magnetic properties and different heat contents. It is largely a matter of definition as to whether we shall call them two different allotropic forms.

Again in regard to the point A of Fig. 1, it is certain that the point A is only a very short distance above or below the F_3C liquid solution line. We do not consider the question of its location settled.

In short, in putting out the modification of the iron-carbon diagram for 1 per cent silicon iron which we have shown in Fig. 1, we wish to state that we do not consider that we have settled either of the above questions. Our entire purpose in presenting Fig. 1 was to give a diagram that would be as useful as possible as a guide in the annealing process. It is based only upon such experimental facts as are at present available. The two points mentioned above in regard to the pure iron-carbon system are just as much in doubt in our Fig. 1 as they are in the pure system.

In regard to the location of the A_3 line in Fig. 1, we might state that if we take the value 0.57 per cent (Schwartz data) as the carbon content of the iron-carbon eutectoid and a temperature of 771 degrees Cent. (which is the value obtained by H. E. Flanders and E. E. Moore at Iowa State College), and again if we take the value of 0.64 per cent (Schwartz data) as the carbon content of the solid solution in equilibrium with pearlite at a temperature of 758 degrees Cent. and plot these two points, they fall upon the A_3 line as we have drawn it, i. e., a line drawn through C and J of Fig. 1 will intercept the zero carbon line at very nearly 900 degrees Cent. As a matter of fact, we accepted 900 degrees Cent. as the A_3 transition point in 1 per cent silicon alloys for reasons to be noted later, and drew the A_{2-3} line as explained in the note to diagram, Fig. 1, of this paper. We consider this the best evidence

available that the A_1 stable and A_1 metastable points occur on the same A_3 line.

One might at first thought be inclined to conclude that if the two eutectoids occur on the same A_3 line that this is proof of only one body existing in the solid solution. Yet it can be shown that this may not necessarily follow.

Thus there is ample proof that in liquid solutions of sodium sulfate there are several forms of the solute existing in solution in equilibrium with each other. It is possible by properly controlling the condition of cooling to have $Na_2SO_4 7H_2O$ crystallize from the solution, while under other conditions $Na_2SO_4 10H_2O$ may be precipitated. It is assumed that there is an equilibrium between these two forms as well as others in the solution. Since the $Na_2SO_4 10H_2O$ has a tendency to supersaturate it is possible to exceed the solubility of $Na_2SO_4 7H_2O$ before $Na_2SO_4 10H_2O$ crystallizes. The result is that the $Na_2SO_4 10H_2O$ precipitates.

In the crystalline state of aggregation, as in the case of Austenite, it is difficult to picture the possible nature of two solid solutions, one Fe_3C in gamma iron, the other C in gamma iron.

The thing of importance to note here is that the existence of A_1 stable and A_1 metastable on the same A_3 line does not prove the existence of only one body in solid solution, but it does indicate that if two different bodies which for the sake of clarity we might indicate as Fe^3C in gamma iron and C in gamma iron, do exist, that these two bodies are in equilibrium with each other in the solid soluton. Further, if two such bodies do exist, the fact that we may start with carbon and iron and obtain the metastable body Fe_3C, or if we start with Fe_3C, we obtain the stable bodies Fe and C, also indicates that, if two bodies do exist in solid solution they are in equilibrium with each other.

After very careful study of the data[1] presented by Mr. Schwartz and co-workers, we are forced to say that we fail to recognize any proof of there being two distinct A_3 lines, one for the metastable system and the other for the stable system. In Mr. Meacham's work, which was carried out in Mr. Schwartz's Laboratory, Mr. Meacham states[2] in conclusion: "So far as this problem was carried nothing definite was learned about the A_3 point except that with the addition of silicon it becomes very faint and difficult to follow."

As we understand Fig. 1 of the first reference, a minimum value for the carbon content of pearlite in a 1 per cent silicon white iron is the carbon value for a point on the A_3 line of the pure iron carbon diagram corresponding to the temperature determined for the A_1 metastable transition in a 1 per cent silicon iron. This is the method used by Schwartz to determine the lower A_1 metastable line in Fig. 1 of the reference. This, in short, amounts to saying that the temperature of the A_1 metastable point is known but its carbon content is not, since the car-

[1]Transactions, Institute of Mining and Metallurgical Engineers, vol. LXIX, p. 791.
[2]Transactions, A. S. S. T., vol. 4, No. 5, p. 646.

bon content value is based upon an assumption. Even if the carbon content of pearlite were known for various silicon contents this information alone would give no indication of the slope of the A_3 line for any particular silicon content because the slope of the A_3 line may change with the silicon content.

It seems clear, therefore, that an experimental determination of the carbon content of pearlite in a 1 per cent silicon iron is needed, and, in addition, the determination of the A_3 point for an iron of this same silicon content and for carbon contents from 0 to about 0.3 per cent. With this data the A_3 line for the metastable system could be drawn.

Substantiating our location of the A_3 point at 900 degrees Cent. in 1 per cent silicon alloys, we offer the following quotations from references which have been cited by Mr. Schwartz. Gontermann[3], in reviewing previous work, states definitely "In Osmond's alloys the temperature of transformation from gamma to beta iron was almost independent of the silicon percentage." Gontermann's diagram, reproduced by Yensen[4], shows only a very slight rise in the temperature of the A_3 transition, as silicon increases, even up to 8 per cent. Charpy and Cornu-Thenard[5] make the following statement in their summary: "The authors are able to confirm as different observers have pointed out, that the A_3 point rapidly decreases (*in intensity*) when the percentage of silicon rises, at the same time rising very slightly on the temperature scale."

In regard to the machinability of the intermediate products, we assumed that everyone would recognize the fact that they would not machine as readily as completely malleablized material. Yet, as we have pointed out elsewhere, they can be successfully machined. Whether or not they should be machined will, of course, be determined by their value for fulfilling certain useful specifications.

We feel that the attitude taken by Mr. Schwartz and Mr. Bean, "That any demand for these intermediate products must come from the trade," is one which is too conservative.

There are numerous examples, only one of which we wish to mention, which show that a more aggressive attitude toward putting a new product on the market sometimes results in a very great source of income.

We have in mind the problem the Quaker Oats Company solved recently in regard to a possible utilization, of oat hulls of which they were burdened with very great quantities. The problem was taken up by the Miner Laboratories of Chicago and it was found that very large quantities of a liquid known as furfural could be obtained. The great difficulty was that at this time there were no known uses for this liquid. Instead of waiting for a demand to come from the trade, the Quaker Oats Corporation instructed the chemists to find out what uses could be made of furfural.

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[3]Journal Iron and Steel Inst., 1911, No. 1, p. 432.
[4]Uni. of Illinois Eng. Experiment Station Bull., No. 83, p. 16.
[5]Journal Iron and Steel Inst., No. 1, 1915, p. 301.

The result has been that it turns out to be a valuable solvent for many purposes and it has the properties of a powerful disinfectant. It also has proven to be of very great importance in the manufacture of plastics and organic chemicals.

We believe that the properties of these intermediate products and the ease with which they may be produced warrants a search for possible uses. It is not to be expected that they are suitable to displace the uses of malleable iron where the very great softness of completely malleableized material is required. There are, however, many specifications where a higher yield point and a higher tensile strength than that of normal malleable iron are required, and where a somewhat lower shock resistance would be allowable.

Oxidation Losses During Air Furnace Melting of White Cast Iron

By H. A. Schwartz, Cleveland, Ohio

A knowledge of the rates of oxidation of the several elements in white cast iron is of importance, metallurgically, for the control of chemical composition, and commercially, for estimating the cost of the material converted, unavoidably, into slag. On both accounts, it is desirable to reduce these oxidation losses as far as possible, and to keep them as nearly constant as may be.

The purpose of the present paper is to study, though perhaps imperfectly, and incompletely, the mechanism and degree of oxidation, rather than to devise, or record, means for controlling it.

The elements which are oxidizable under the postulated conditions are carbon, silicon, manganese and iron. All malleable founders who analyze, as they should, each heat for the first three elements, have at hand the data for determining the first three losses. The loss in iron is not so readily obtainable, since it is not recorded directly as a change of composition during melting. Attempts to determine it by calculations founded on the total weight of melting stock used, and of the castings and sprue produced, are not very dependable, owing to the great chances of error in the many weighings, and in the recovery of iron from the slag, furnace bottoms, gangways, and so on. Actually, the iron loss is the largest of the four, and therefore, financially, the most important. It is somewhat readily obtained if we know the analysis of the slag produced. This slag contains all the manganese and all the iron which was oxidized. Whether or not we recover and weigh all the slag, providing only we obtain a truly representative sample, we can calculate from the ratio of iron to manganese in the slag, and from the decrease in manganese con-

tent of the iron, the weight of iron oxidized per unit weight charged.

For all ordinary purposes it is sufficiently accurate to multiply the manganese loss in melting by the ratio of iron to manganese in the slag, to obtain the iron loss. If allowance is to be made for the fact that the manganese in the finished heat is less than that charged, not only in proportion as its percentage is reduced, but also because the total weight of metal is reduced, then a more complex algebraic calculation can readily be made. It is assumed that the slag sample is freed from mechanically entrapped metallic iron. If we add together perfectly accurate figures for weight of castings, weight of sprue, and oxidation loss, the sum must be less than the weight charged, for it is inconceivable that a perfect recovery of all shot iron, drops, and so on, should be made.

We all know that if a piece of cast iron is heated, red hot, in an oxidizing atmosphere, it becomes covered with scale. This scale is either ferrous oxide (FeO), mangnetic oxide (Fe_3O_4) or ferric oxide (Fe_2O_3), depending upon the composition of the gases and their temperature, and pressure. The problem of the gas phase in equilibrium, with each of these oxides at any given temperature, has been quite thoroughly studied by many workers. Some of the facts have been summarized elsewhere* by the writer and need not be repeated. Under almost any commercial conditions the product is magnetic oxide (Fe_3O_4) which, on analysis, would be reported as consisting of Fe_2O_3 and FeO in equal (molecular) amounts, or in the ratio of 160 to 72, or 2.22 to 1 by weight.

In due time there would result in commercial air furnace melting, a bath of iron covered by a layer of melted Fe_3O_4, containing also oxides of Mn and Si in negligible amount. Both layers being liquid, convection currents sooner or later bring all parts of one into contact with all parts of the other at the surface of contact. The molten Fe_3O_4 can quite readily oxidize silicon, for example, by giving up part of its oxygen. It may be possible that the FeO can not give up oxygen in this manner, when combined with SiO_2, but Fe_2O_3 can. The reaction, disregarding the

*Page 230 *American Malleable Cast Iron*. H. A. Schwartz, 1923. Penton Pub. Co., Cleveland.

question of whether silicon is present as such, or as a silicide, is

$$2\ Fe_2O_3 + Si = SiO_2 + 4\ FeO$$

and immediately the following reaction also takes place, either with the SiO_2 so formed, or SiO_2 from the refractories.

$$SiO_2 + FeO = FeSiO_3$$

A very similar reaction also occurs with carbon, except that the CO and CO_2 formed pass into the gas stream and do not combine with ferrous oxide.

Such reactions tend to impoverish the slag in Fe_2O_3 as compared with FeO, and may throw it out of equilibrium with the gas phase. The products of combustion will then re-oxidize part of the FeO, present in silicates, to Fe_2O_3, and the process goes on, the slag transferring oxygen from the flame to the constituents of the molten cast iron. If the temperature, pressure, and composition of products of combustion remain constant, the slag and metal would try to reach a composition in equilibrium therewith, and with each other.

The slags of commercial air furnace practice are $FeOSiO_2$ mixed with rather small amounts of $Fe_2O_3(SiO_2)_3$ and $MnOSiO_2$. Ferrous silicate $FeOSiO_2$ is reducible by solid carbon, and a furnace which is blowing coal may cause a liberation of silicon and iron from the slag, and their passage into the metal, the reaction being some combination of the following:

$$FeOSiO_2 + 3C = Fe + Si + 3CO$$
$$2\ FeOSiO_2 + 3C = 2Fe + 2Si + 3CO_2$$

Any examination as to the equilibria in such complicated systems as are here considered, would become far too involved for successful general discussion. In the simplest conception we have three phases: the flue gas, the liquid slag, and the liquid metal, and at least five components, iron, carbon, silicon, manganese, and oxygen, beside the possibility of some chemical compounds requiring consideration as components entering unaltered into the reactions. Leaving aside this intensely interesting, though speculative consideration, we may turn to certain experimental facts which may give us some guide as to what may be expected in practice.

Some years ago the writer collected data and slag samples from five plants. Four were operated by the company with

Table 1

Oxidation Losses in Air Furnace Melting in Per Cent of Total Weight Charged

Series	1	2	3	4	5	6
Fe	1.17	1.16	1.01	1.24	(?)	.86
Mn	.30	.29	.24	.21	.22	.21
Si	.42	.30	.27	.34	.31	.32
C	.62	.60	.56	.71	.47	.50

Table 2

Compositions of Air Furnace Slags

No.	FeO Per cent	Fe_2O_3 Per cent	MnO Per cent	SiO_2 Per cent	Al_2O_3 by Difference Per cent	Total Fe Per cent	Mn Per cent
1	29.54	6.430	3.36	54.00	6.67	27.4	2.60
2	33.54	2.440	2.54	47.08	14.40	27.7	1.97
3	28.25	2.000	4.24	52.12	13.39	23.4	3.28
4	29.67	1.000	4.70	52.28	13.35	23.7	3.65
5	30.44	0.858	4.06	52.60	12.04	24.1	3.15
6	33.66	0.429	3.52	49.60	9.92	26.3	2.73
7	33.92	0.572	3.35	48.84	13.32	26.7	2.60
8	35.21	0.572	5.36	48.00	10.86	27.7	4.16
9	35.08	1.280	3.87	49.84	9.93	28.1	2.99
10	34.70	1.430	4.00	48.84	11.03	27.9	3.09
11	35.86	1.430	2.85	46.88	12.98	28.7	2.21
12	35.86	1.570	2.58	46.72	13.27	28.9	2.00
13	36.50	0.858	3.69	47.40	11.56	28.8	2.86
14	35.60	2.560	2.79	50.68	8.37	29.2	2.94
15	35.34	0.858	5.04	50.24	8.49	28.0	3.90
16	34.80	1.860	4.69	50.60	8.05	28.2	3.64
17	34.80	2.560	4.19	48.40	10.05	28.8	3.25
18	35.08	2.720	3.87	50.16	8.17	29.0	2.99
19	35.21	1.730	5.04	49.20	15.82	28.5	3.90
20	34.70	1.730	4.18	49.08	10.31	28.0	3.21

Table 3

Elements Lost by Oxidation During Melting in Per Cent of Original Charge

No.	No. of Heats	Si	Mn	C	Fe
1	1	.34	.14	.94	1.47
2	1	.30	.15	.10	2.10
3	2	.34	.16	.61	1.14
4	3	.37	.16	.73	1.04
5	3	.42	.17	.78	1.25
6	5	.42	.20	.67	1.93
7	8	.46	.21	.67	2.16
8	13	.53	.20	.60	1.33
9	6	.66	.21	.51	1.97
10	8	.60	.22	.52	1.99
11	9	.55	.23	.47	2.97
12	5	.56	.23	.55	3.32
13	8	.62	.23	.54	2.32
14	7	.66	.24	.57	2.36
15	3	.71	.25	.40	1.79
16	9	.65	.25	.61	1.94
17	3	.64	.25	.43	2.22
18	1	.79	.26	.80	2.52
19	1	.74	.29	.47	2.12
20	3	.71	.28	.80	2.45

which he is connected, but at that time, only one was under his direct supervision. The data covered a period of one year. The fifth plant, in which only a short test was made, merely granted an opportunity for studying its processes, which were in no degree influenced by any opinions but its own. There was also available a partial study made of the practice of one of this company's plants some years earlier, at a time when melting operations were supervised by an entirely different personnel.

The observed oxidation losses were as shown in Table 1.

To the writer it was then, and is now, surprising that without any systematic supervision, these losses should have been so nearly constant under conditions which might well have varied widely. It is very probable that this result is entirely due to the large number of heats in the averages in the first four columns.

It is also true that the appearance of the air furnace flame is a somewhat sensitive indicator of its composition. Experience has shown that in furnaces working normally there should be at most 2 per cent of free oxygen, and preferably much less when the gases leave the metal. At the front of the furnace where combustion is not yet complete, somewhat more may be tolerated if absolutely unavoidable, and if accompanied by more than enough CO to combine with it. To secure these results, there will be even at the end of the furnace from 2 to 6 per cent CO, accompanying, say, 12 per cent of CO_2. Any attempt to alter this ratio of CO_2 to CO is immediately counteracted by an absorption of O by the constituents of the metal. Four or 5 per cent O, with CO below 2 per cent, is pretty likely to produce sufficient oxidation to make the furnace incapable of producing a usuable product.

A year ago August Van Lantschoot, of the Iowa Malleable Iron Co., contributed to the program of the American Foundrymen's association a paper* in which he described the application of fuel oil to the melting operation. It was there clearly shown that oxidation in melting was very uniform, indeed, over long periods of time, and also, that these losses could be varied at will by the operator.

It seemed that this constituted a condition ideally suited to the study of the relative oxidation rates of the several elements

*Van Lantschoot, A. *Application of Fuel Oil to the Malleable Air Furnace.* Transactions A. F. A., vol. 31, pp. 265-286.

Table 4

Oxygen Absorbed by the Several Elements During Melting in Per Cent of Weight of Metal Charged

No.	By Si	By Mn	By C	By Fe	Total
1	.39	.04	1.25	.46	2.14
2	.34	.05	.13	.62	1.14
3	.39	.05	.81	.33	1.58
4	.42	.05	.97	.30	1.74
5	.48	.05	1.04	.36	1.93
6	.48	.06	.89	.55	1.98
7	.53	.06	.89	.63	2.11
8	.61	.06	.80	.38	1.85
9	.75	.06	.68	.57	2.06
10	.69	.07	.69	.57	2.02
11	.61	.07	.63	.87	2.18
12	.64	.07	.73	.97	2.41
13	.71	.07	.72	.67	2.17
14	.75	.07	.76	.70	2.28
15	.81	.08	.53	.51	1.93
16	.74	.08	.81	.57	2.20
17	.73	.08	.57	.65	2.03
18	.90	.08	.97	.74	2.69
19	.85	.09	.63	.63	2.20
20	.81	.08	1.07	.72	2.68

of the charge. Mr. Van Lantschoot kindly undertook the preparation of a series of groups of heats varying in oxidation losses, and the collection of data and slag samples covering these heats. The writer's thanks are due to him, and to the Iowa Malleable, for their courtesy in supplying this material and information. The slags were analyzed in the writer's laboratory by G. M. Guiler and Arthur Wahrenberger, with the results shown in Table 2.

From the results of Table 2 and Mr. Lantschoot's data the oxidation losses have been calculated as shown in Table 3.

It will be at once evident that there is a general agreement that Si and Mn are oxidized nearly in a constant ratio. The iron loss, however, does not bear any close relation to that of the other two elements.

It may be well to express the results in terms of oxygen absorbed by each of the several elements. This can be done by calculations based on the assumption that the products of combustion are:

for Manganese	MnO
for Silicon	SiO_2
for Iron	FeO and Fe_2O_3 in the ratio in which these oxides are found in the slag. The Fe_2O_3 proved generally negligible from this viewpoint.

for Carbon

CO, which is largely an assumption, but is probably justified from what is known as to equilibrial between the system CO-CO_2 and either carbon or cementite. The furnace gases always contain some CO as already indicated, and although they contain much more CO_2, none of this need necessarily have been formed from the metal.

Without any careful calculations, we can see at once that the very simple reaction previously outlined, in which all the oxygen originally combines with iron, and later leaves the iron silicate to unite with Si, Mn, etc., can not explain the facts. Even making allowance for the .01 or .02 per cent oxygen combining with the silicon in the iron, which is first burned, and even neglecting the fact that a little of the iron in the slag is already Fe_2O_3, the oxygen combined with Si, Mn, and C is more than one-half that combined with the iron, which is the limit of additional oxygen with which the amount of that element in the slag could possibly have been combined. We must then assume either that FeO, as existing in slags, can oxidize Mn, Si, or C, in molten iron, being itself reduced to Fe, or that the process of transfer of oxygen from gas to slag and from slag to iron takes place.

When the flame oxidizes the slag, and the slag the iron, there might be expected to result in the more oxidizing conditions, an accumulation of excess oxygen in the slag in the form of Fe_2O_3. Assuming that the amount of oxidizing agent (O or CO_2) in the flame, and of reducing agent (Si, Mn and C) in the iron was not greatly affected by changes in composition of slag, the rate of conversion of FeO to Fe_2O_3 by the gas would grow slower the less FeO remained in the slag, while the rate of formation of FeO from Fe_2O_3 would grow slower the less Fe_2O_3 remained unreduced. There will thus be some ratio of FeO to Fe_2O_3 at which the two reactions will exactly balance.

In Table 5 the weight of slag per unit of metal has been calculated on the assumption that all the manganese lost to the iron appears in the slag, and hence, the weight of slag must be to that of metal as the loss of manganese in the metal is to the manganese content of the slag. Knowing the ratio of slag to

Table 5

Total Weight of Slag, Total Oxygen Combined With Iron in Slag, Excess Oxygen Above That Required to Form FeO, and Oxygen Consumed in Oxidation, All in Per Cent of Original Charge, and Ratio of Fe_2O_3 to FeO and Fe_2O_3

No.	Weight of Slag	O in Fe and Fe_2O_3	O in Fe_2O_3 Above FeO	O Consumed	$\frac{Fe_2O_3}{FeO \text{ and } Fe_2O_3}$
1.....	5.4	.46	.035	2.14	.18
2.....	7.6	.62	.018	1.14	.07—
3.....	4.9	.33	.011	1.58	.07—
4.....	4.4	.30	.004	1.74	.03+
5.....	5.4	.36	.005	1.93	.03—
6.....	7.3	.55	.003	1.98	.01+
7.....	8.1	.63	.006	2.11	.02—
8.....	4.8	.68	.003	1.85	.02—
9.....	7.0	.57	.010	2.06	.02—
10.....	7.1	.57	.011	2.02	.03+
11.....	10.8	.87	.015	2.18	.04—
12.....	11.5	.97	.020	2.41	.04+
13.....	8.1	.67	.007	2.17	.02+
14.....	8.1	.70	.020	2.28	.07—
15.....	6.4	.51	.006	1.93	.02+
16.....	6.8	.57	.013	2.20	.05+
17.....	7.7	.65	.020	2.03	.07—
18.....	8.4	.74	.023	2.69	.07+
19.....	7.4	.63	.015	2.20	.05—
20.....	8.7	.72	.016	2.68	.05—

metal, we can readily calculate the oxygen content of the slag in relation to the metal, from the known FeO and Fe_2O_3 contents of the slag.

It is here shown that the amount of slag formed, in general, increases with the oxidation losses. This relation would be axiomatic except for the fusion of refractories, which add to the Al_2O_3 and SiO_2 content of the slag.

Since Table 2 shows a somewhat constant iron content for all the slags, and a relatively small amount of Fe_2O_3, it follows naturally that the oxygen combined with iron also tends to increase with increasing oxidation losses. There is only, at most, a slight tendency for the excess of oxygen in Fe_2O_3, above that required, to from FeO, to increase toward the lower end of the table. The ration of FeO to FeO+Fe_2O_3 is also somewhat constant. There is, perhaps, a tendency to a minimum about the second quarter of the table.

It may be interesting to study the effect of the increased reducing power of the metal due to higher initial content of oxidizable elements by calculating the oxygen absorbed per unit weight of each element originally present. Such a calculation may be made by dividing the figures in Table 4 by the content

Table 6

Oxygen Absorbed by the Several Elements in Per Cent of the Amount of Each Originally Present

No.	Si	Mn	C	Fe
1	24+	8+	40	.48—
2	21+	10+	4	.65+
3	25	11—	28	.35—
4	29—	10+	32+	.32—
5	30+	10—	36—	.38—
6	31+	12	30+	.58+
7	38—	13+	30	.66+
8	42+	13+	27—	.40+
9	46—	13—	24—	.60+
10	45+	15—	23—	.60+
11	41+	14—	21+	.92—
12	44—	15—	24+	1.02+
13	46+	15—	24—	.71+
14	51+	16—	25—	.74+
15	50—	17—	18+	.54—
16	50—	16	27—	.60+
17	51+	17+	20—	.68+
18	57—	17+	31—	.78—
19	53—	19—	22—	.66+
20	54—	18—	36—	.76—

of the original charge, in the corresponding elements. This has been done, and the results tabulated in Table 6.

This table furnishes a very clear means of comparing the tendency of the five elements to absorb oxygen. The oxygen consumed by Si and Mn increases from the arrangement of the table, as we go down the column, the oxygen absorbed by carbon (to CO) is somewhat irregular. The oxygen absorbed by iron is very small compared with all the others, somewhat irregular, and shows a rough tendency to increase at least as far as the third quarter of the table.

It is possible that under more strongly oxidizing conditions, such as are found toward the bottom of the table, some carbon is burned to CO_2, which would increase the oxygen consumption of that element toward the bottom of the table. This, however, is purely speculative.

Reference has repeatedly been made to the possibility that all the oxygen consumed by oxidation is first combined with iron, to Fe_3O_4, with a subsequent reduction of this compound to FeO or Fe, by the other elements.

In Table 7 the total oxygens of Table 4 have been calculated over into their equivalent in terms of Fe, in the compound Fe_3O_4, and compared with the iron remaining oxidized in the slag.

It will be seen that, although the table is arranged in such an order that the oxidation of Si and Mn increase as we read down,

Table 7

Iron Equivalent as Fe_3O_4 to the Oxygen Absorbed in Melting, Iron Actually Remaining in Slag, Iron Possibly Reduced by Si, Mn, and C, and O Absorbed by These Elements in Per Cent of Weight of Charge

No.	Fe as Fe_3O_4	Actual Iron	Reduced After Previous Oxidation	Absorbed by C, Si and Mn
1	5.62	1.47	4.15	1.68
2	2.92	2.10	.82	.52
3	4.17	1.14	3.03	1.25
4	4.56	1.04	3.52	1.44
5	5.06	1.25	3.81	1.57
6	5.19	1.93	3.26	1.43
7	5.52	2.16	3.36	1.48
8	4.85	1.33	3.52	1.47
9	5.40	1.97	3.53	1.49
10	5.30	1.99	3.31	1.45
11	5.72	2.97	2.75	1.31
12	6.33	3.32	3.01	1.44
13	5.71	2.32	3.39	1.50
14	5.97	2.36	3.61	1.58
15	5.06	1.79	3.27	1.32
16	5.77	1.94	3.83	1.63
17	5.32	2.22	3.10	1.38
18	7.05	2.52	4.53	1.95
19	5.77	2.12	3.65	1.57
20	7.02	2.45	4.57	1.96

the oxygen absorbed by C, Si, and Mn, does not increase; i. e., the decreased oxygen absorbed by carbon counterbalances the increase in that absorbed by the other two elements. The reduced iron shows a somewhat general agreement with the oxygen absorbed by the three elements. This agreement, however, proves nothing regarding the validity of our hypothesis, for the reduced iron was calculated from data involving the figures in the last column. The somewhat small variations in the first column, however, are interesting as pointing to a much greater constancy of initial iron oxidation than would be expected from the great variations in silicon and manganese oxidation.

The author fully realizes the difficulty of so organizing the data of the present investigation as to permit of a presentation which shall be both comprehensive and intelligible. Supplementing the tabular matter already presented, certain aspects of the problem are presented graphically in the following charts, which may facilitate comparisons.

Fig. 1 shows the relation of the silicon loss, plotted as the abscissa to the loss of carbon, manganese, and iron plotted as ordinates. It is quite evident that the mechanism involved in the oxidation of all except carbon must be quite similar, for the

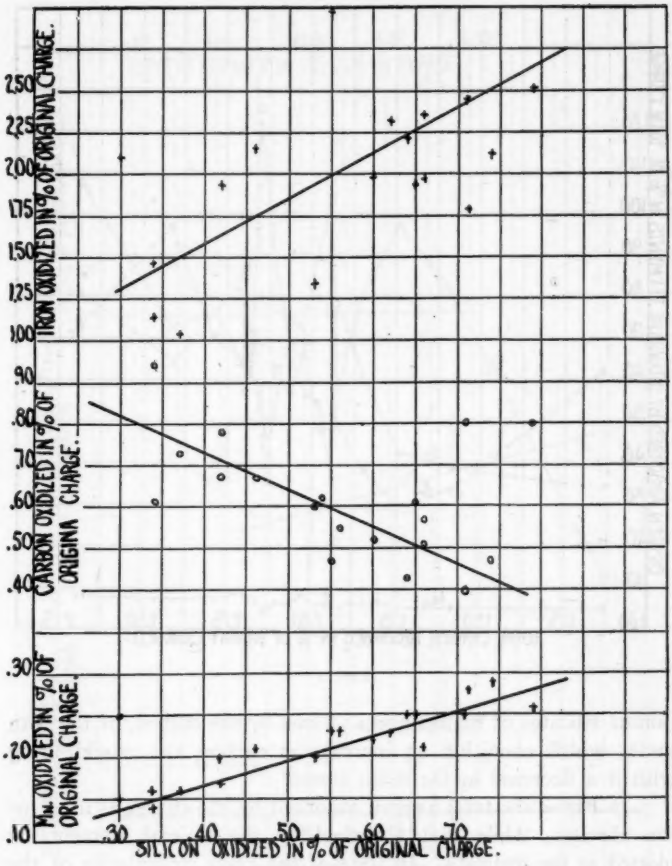

FIG. 1

manganese and iron losses bear an approximately linear relation to the silicon loss. The straight lines in both cases intersect the ordinate at zero silicon, at a positive value, which seems to show that the metallic elements are oxidized to some extent before the oxidation of silicon begins.

The oxidation of carbon, however, decreases as that of silicon, manganese and iron increases, which suggests the reduc-

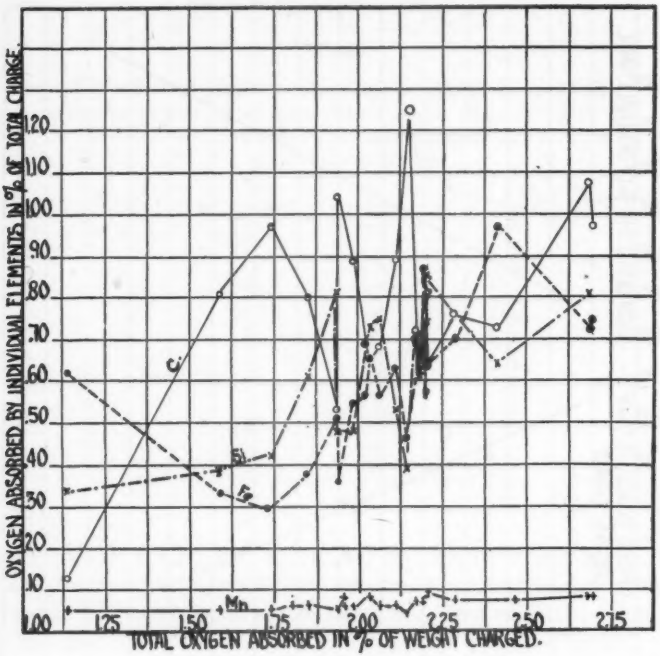

FIG. 2

tion of silicates of manganese and iron by the carbon, of the bath under which condition an increase in carbon loss would bring with it a decrease in the other losses.

In Fig. 2 the total oxygen absorbed by the charge is used for the abscissa, while that absorbed by the several elements is plotted as the ordinate. In spite of the great irregularity of the lines, it will be seen that the oxygen absorbed by each element increases as the total oxidation increases. The left hand point on each line, representing group 2 (one heat only) is rather anomalous, and should probably be excluded. It will be observed that oxygen absorbed by carbon increases much less rapidly than is the case for iron and silicon. The oxygen consumed by manganese increases steadily, but owing to the small amount of that element, the effect on oxygen consumption is but slight.

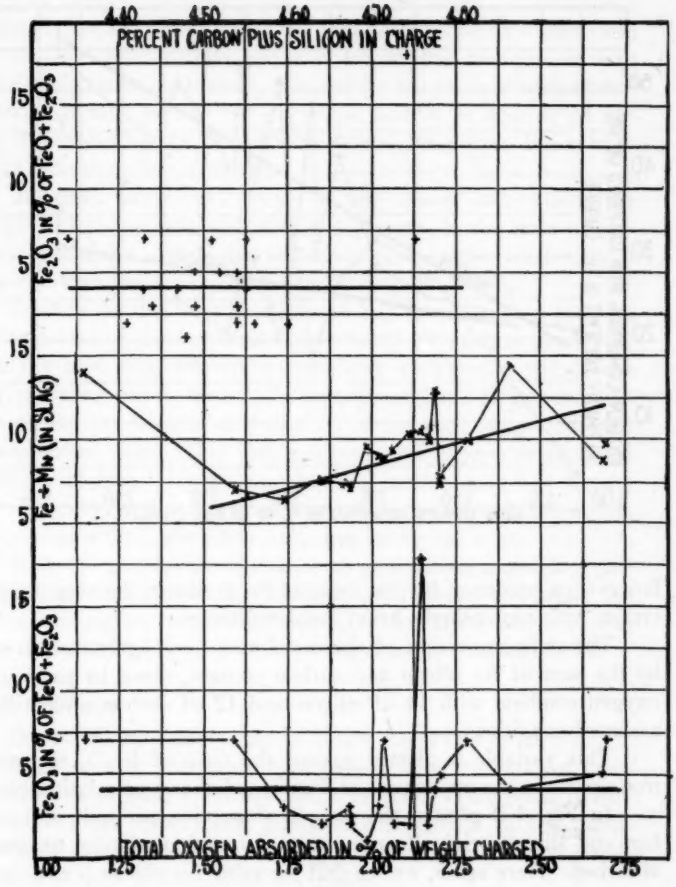

FIG. 3

In Fig. 3 the effect of increased oxidation upon slag composition is graphically shown in the two lower curves. It is quite evident that this variable does not, consistently, affect the degree of oxidation of the iron in the slag, as measured by the proportion of the total iron present as Fe_2O_3 instead of FeO. There is,

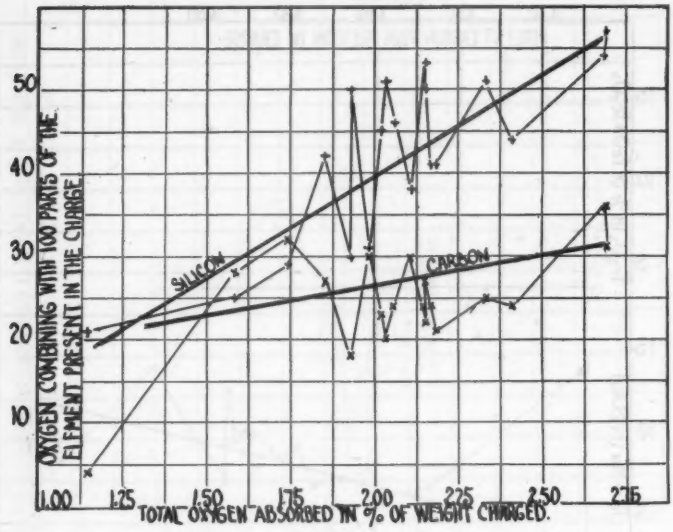

FIG. 4

however, a tendency for the ratio of Fe to Mn in the slag to increase with increasingly heavy total oxidation.

The reducing action of the metal may be roughly measured by the sum of its silicon and carbon content, since 16 parts of oxygen combine with 14 of silicon and 12 of carbon under the assumed conditions.

This variable is plotted against the ratio of Fe_2O_3 to total iron oxides in the upper part of Fig. 3, and shows no relationship.

In Fig. 4 is plotted the oxygen absorption per unit of carbon and silicon originally present as a function of total oxygen absorbed. Here again, we see that the value for silicon is affected much more rapidly than that of carbon.

It is questionable whether the present investigation warrants any very sweeping conclusions. It seems that within an ordinary range of operating conditions, the composition of the slag, excluding contamination from refractories, is but slightly affected by changes in the oxidizing or reducing conditions. The extra oxidation thus results merely in a greater amount of slag.

It seems further that some condition, not here determined,

influences the distribution of oxygen between carbon on the one hand, or silicon, manganese and iron on the other. It was noted especially by Mr. Van Lantschoot that heats made on a new sand bottom lost more carbon and less silicon and manganese than those made on an old bottom. The author has made similar observations. It may be that the degree of acidity or basicity of the slag influenced by the presence of molten SiO_2 from the refractories influences this selection.

It seems likely that carbon in the charge can reduce the silicates of manganese and iron here present, to the state of elementary Mn, Fe, and Si, but that none of the other elements can do more than reduce them to $FeOSiO_2$ or $MnOSiO_2$.

In view of the large amounts of Fe_3O_4 required to produce all the oxidation required under the present circumstances coupled with the preceding assumption that only carbon can reduce the corresponding silicate to metallic iron, the author's earlier assumption of the mechanism of oxidation is not well supported, and it now seems more likely that a transfer of oxygen from flame to slag, and from slag to iron goes on continuously. If so, the slag composition is an expression of the relation between the oxygen input from the flame and removal by the iron.

It is, of course, conceivable as an alternative, to the last two suggestions, that carbon is, during melting down, constantly reducing iron oxides originally formed, so that at no time are such large amounts of Fe_3O_4 present as required by the calculation.

Author's Note:

Dr. R. S. McCaffery has privately suggested to the writer the importance of temperature in determining the relative rates of oxidation in such a system as the present. This point is evidently of great importance, and was disregarded in the paper principally because under the shop conditions, there considered, the temperature is continuously variable.

It may be said for purposes of record, that oxidation of the charge begins at temperatures around 600 degrees Cent. and that most of the slag is formed and removed by the time the temperature has risen to 1200 degrees Cent. or a little more. This variation in temperature is, perhaps, one of the factors preventing a systematic and logical treatment of the data.

Powdered Coal in a Malleable Casting Plant

By F. L. Wolf and Wm. Romanoff, Mansfield, Ohio

For many years the statement has been heard made, by the powdered coal equipment manufacturers, that powdered coal was here. A new method had been found to extract the maximum number of heat units from one of our oldest fuels, coal. We, at the plant with which the writers are connected, in addition to many others, were skeptical. Considering the fact that a tremendous amount of money had to be expended for initial installation before we could begin to derive benefits from this method of coal combustion, we had a right to be. While not belittling the possibilities, we wanted to be shown more than merely the optimistic propaganda of those exploiting this method.

Several years ago our firm decided to build a new malleable iron plant. When the question of fuel arose, we made a thorough investigation, visiting many of the larger plants in this country and, after considerable thought, decided to try powdered coal. Now, after three years of trial, we not only agree with the powdered coal equipment manufacturers in their statement that powdered coal is here, but we believe that it is here to stay.

Applications of Powdered Coal

In considering the applications of powdered coal, we shall merely consider them as they apply to our own plant. In any application, the coal demand must be large enough to warrant installation. We employ powdered coal for the melting and annealing of white iron and in our boiler house. At one time, we baked our sand cores with powdered coal, but at present we are using oil as a fuel. We did not make this change because we found that oil combustion was cheaper or more efficient but because in burning pulverized coal a film of ash was deposited

upon the cores. Upon inspection for fins or other defects in cores, this film of ash had to be brushed off with consequent high loss due to excessive breakage. Sand core breakage is ordinarily large enough without subjecting the core to further hazard by removing the ash. In order to obtain a cleaner core, although not necessarily a better-baked core, we decided to utilize oil for baking.

Suitable Coals

In discussing the subject of coals suitable for pulverizing and burning, we feel that we are treading upon dangerous territory. From what we could gather from various writers and those interested in the sale of pulverized coal equipment, we were given the impression that almost any grade of coal could be used. In fact, after speaking to some powdered coal enthusiasts, we wondered why the ash was discarded on the dump pile at all. Why not pass it through the furnace and re-use it by this wonder system? But after three years of experience in powdered coal, we are more enthusiastic than ever regarding its use, even though we found to our regret that many misleading statements regarding suitable coals are prevalent in the literature.

You probably wonder whether the writers are qualified to make such a statement. Since the installation of our powdered coal plant, we were unfortunate enough to run short of coal during the miners' strike of 1922. Like a number of other consumers we were so desperately in need of coal that we were willing to pay a premium for any black substance that resembled coal and would burn. We used coals with ash contents varying from 2 per cent minimum to 21 per cent maximum, with moisture as high as 12 per cent and sulphur as high as 2 per cent. The moisture could be dried out. At the furnace a reasonable amount of sulphur could be taken care of by adding enough manganese to the metal to offset its deleterious effects, but as to the ash:—if we were certain that everyone here had had experience in the operation of a melting furnace fired by powdered coal, there would be no need for this discussion. You would simply admit the futility of trying to melt iron success-

fully and economically with coal of high ash content, particularly if the latter had a low fusing point. It is continually covering the bath forming an insulating slag and necessitating continuous skimming in order to permit the absorption of the heat by the metal. In addition, the sticky ash adheres to the bungs and bridge wall, reducing the opening between the bridge wall and bungs and setting up a tremendous back pressure which not only makes it very uncomfortable for the furnace men due to the long flame shooting out of the openings of the furnace, but also plays havoc with the refractories. If the opening above the bridge wall is made larger to take care of this condition, an excessive draft results which lowers the efficiency by sucking in cold air through the furnace openings, which in turn chills the metal in passing over same and which also causes some combustion to take place beyond the metal bath instead of on the bath. After each heat, the bungs must be raised above the bridge wall and the sticky ash cleared away. This work is very hot and the furnace men suffer considerable mental and physical hardship. In addition to this there is the delay in melting and the disagreeable feeling of the tired molders and laborers who are forced to wait for the metal after completing a hard day's work.

In the annealing ovens, the ash plugs up the flues with very undesirable results, while in steam boiler practice, low fusing point ash will stick to the boiler tubes, thus insulating same from the heat and decreasing the efficiency of the plant.

At present we are burning a good grade of Kentucky coal and we are obtaining an average ratio of three pounds of metal melted per pound of pulverized coal consumed. There are isolated cases where this ratio has gone as high as 4¼ to 1. In the annealing process an average ratio of 3¼ to 4 pounds of iron per pound of coal is obtained. Both our melting and annealing coal ratios are considered good practice. We feel that ash is the most detrimental impurity in coal. This is particularly true in melting if the ash content exceeds 8 or 10 per cent and has a low fusing point. We mention this in all sincerity for the benefit of those who are contemplating the installation of a powdered coal plant and are expecting considerable economy by the use of a cheaper grade of fuel.

Theory of Powdered Coal

Gaseous fuels are ideal. They can be conveniently distributed, are easily mixed with the necessary oxygen to produce complete combustion and give rise to splendid working conditions. Oil also falls into this class. It is easily atomized and its particles so finely divided that they approach a gas in behavior when combined with the proper amount of air.

Coal, on the other hand, is usually burned in mass form. Combustion is slow and incomplete and an excess of air is required, the cooling effect of which often neutralizes the effect of a more perfect combustion. Consider a cubic inch of coal, for instance, when burned on a grate. Six square inches of surface are exposed for combustion. Oxidation proceeds slowly from the surface inward, large excesses of air are required and much carbon is trapped in the ash. On the other hand, if a cubic inch of coal is pulverized so that 85 per cent will pass a 200 mesh screen, this cubic inch of material will be broken into more than forty-five million particles, exposing approximately thirty square feet of surface for combustion. In other words, the more finely the coal is divided, the more nearly it approaches a gas, and in this extremely fine state of division it can be handled very much like a gas. When the fine particles are surrounded with the proper amount of air, at the ignition temperature, instantaneous and complete combustion takes place with a consequent releasing of all the heat units which the coal contains.

Factors Affecting Powdered Coal Efficiency

We feel that nowhere in a malleable plant can the merits of a powdered coal system better be judged than at the melting furnace. Here is the pulse of the entire system. Just as a good automobile can be put in disrepute by a poor driver, so can reflection be cast upon a good powdered coal system by inefficient furnace design and operation. And by the same token a mediocre powdered coal system can be greatly assisted. We use as a barometer the time of melting and the coal ratio, that is, the pounds of metal melted per pound of coal. These can be affected by the factors which we list under furnace operation.

Furnace Operation

1. Skimming

Whether to permit the slag formed to remain upon the metal bath until pouring is a much discussed question. This slag acts as a coating and prevents considerable oxidation, but we have found that this advantage is greatly offset by the longer period necessary for the metal to reach pouring temperature. There is no question but that slag is a comparative insulator and prevents the heat from reaching the metal. This greatly increases the time of melting in addition to lowering the coal ratio. Our practice is to skim at least three or four times during a heat and the increased oxidation is taken care of by increasing the percentage of constituents added to the original mix. In other words, suppose we desire 80 points of silicon in the finished white iron. In order to obtain this amount we are required to charge 110 points of silicon. Then we find that by constant skimming we are only obtaining 75 points of silicon due to increased oxidation. To offset this added 5 point loss, we merely increase the silicon charged to 115 points.

2. Rabbling

Considerable time can be saved in melting by rabbling or poking the charge when it is almost melted flat. This submerges the unmelted iron into the molten bath and permits the heat of fusion of the molten metal to assist in melting. It also exposes more surface to the heat and is quite an important factor in proper furnace operation.

3. Oxidation

While we always attempt to keep our furnace atmosphere as reducing as possible, still we do not find conditions particularly detrimental in so far as the melting time is concerned with an oxidizing condition. The reaction taking place upon the oxidation of the white iron constituents is exothermic and the heat generated naturally assists in melting. If increased oxidation occurs, it can be taken care of as explained under "skimming."

The only disadvantage in excessive oxidation is the fact that this condition makes the operation of the furnace less "foolproof." It must be closely watched and test plugs must be constantly poured and broken to determine just how far the oxidation of the constituents has proceeded. If the addition of constituents such as silicon or carbon is necessary, it can be taken care of at once instead of waiting until the metal is hot and ready to pour. If the charge is "doped" with silicon, it takes at least twenty or thirty minutes for a thorough intermixing. If the silicon was not, therefore, added at the proper time you can readily see how there would be a subsequent delay, thereby increasing the melting time and necessarily lowering the coal ratio.

4. Coal

The quality of coal used also has a tendency either to increase or decrease the melting time and coal ratio, but this has been thoroughly discussed under "Suitable Coals."

Furnace Design

In designing a furnace for the melting of white iron, more is to be considered than the mere assembly of some steel plates lined with refractories and containing enough space into which to place the charge. For instance, in the reverberatory type of furnace, enough space must be allowed so that practically complete combustion takes place in the effective area. In other words, the heat units liberated must be retained long enough in the furnace so that the maximum quantity is given up to effective work. The factors which effect this condition are so varied that we do not attempt to discuss any one specific design but it all gets back to the fundamentals such as proper hearth space, distance of charge from burner, tonnage of charge, drafts, type of burner, etc.

Conclusion

In passing, we again want to impress you with the fact that our conclusions regarding the use of powdered coal are derived only from our experiences at this one plant. They are not general unless you care to make them so. As evidence of our faith

in the use of pulverized fuel we have, at a considerable expenditure, recently extended its use to our new boiler plant. By the use of suitable coal and proper furnace design and operation we feel that powdered coal can be used in a malleable plant to the satisfaction of even the most critical.

Discussion—Powdered Coal in a Malleable Casting Plant

WM. ROMANOFF: As a preface to this paper I want it understood that the experiences related are simply those encountered by us at the Ohio Brass Company, and I hope you people do not think our conclusions are general, but are merely specific unless they also fit your particular case.

J. H. LANSING: In connection with this interesting paper, I think it would be of interest to us to know whether in using powdered coal, such as has been used at the Ohio Brass plant, there is a decrease in the oxidation loss to such an extent that there can be a material increase in the percentage of pig iron charged.

W. ROMANOFF: In our practice today we use 45 per cent of pig iron and have gone down as low as 40 per cent. We have not experimented to see how much lower we can go, but that all goes back to the fact that the pig iron will also depend on the amount of sprue, or malleable scrap, that is received. We do not buy any malleable scrap or sprue on the outside; we simply use our own. Pig iron would have to be added to make up the difference.

J. H. LANSING: My point was that malleable scrap as a rule is less expensive than pig iron, and therefore if you can buy malleable scrap cheaper than pig iron, why not substitute malleable scrap for pig iron in a certain percentage, if your carbon reduction is low enough so that you can do that?

W. ROMANOFF: In our part of the country there is not much difference between the price of malleable scrap and pig iron, but if we bought malleable from other plants, we would simply have to analyze the various cars we bought, and they would be so mixed up that we would not get the control that is desired.

J. H. LANSING: In our operating experience we have run at times 20 or 25 per cent of foreign malleable scrap; we have not analyzed it and we have had very good results in producing iron according to standard specifications, and I think you strike an average in malleable scrap that you can run along on pretty consistently.

W. ROMANOFF: Would not the percentage of malleable scrap used depend on the size of your casting, the size of your scrap charge in

the furnace? If you were charging a higher percentage of malleable scrap and it all consisted of small pieces, it would probably become a sticky mass in the furnace and be pretty hard to work, particularly as malleable scrap melts last.

J. H. LANSING: I believe that is a question that is linked up with the melting efficiency of your furnace, and that is a point of interest, whether the melting efficiency with powdered coal is greater to such an extent that you can substitute this amount of malleable scrap and melt it and not decrease your carbon to too great an extent.

MR. RYS: I would like to ask the writer of this paper if he uses a top blast or admits air through the burner.

W. ROMANOFF: We use no top blast; it all comes through the burner.

W. R. BEAN: I would like to ask the author if they have figures covering the cost of pulverization, labor, power, maintenance exclusive of fixed charges, and also the capacity of the plant. That is one of the items that must enter into the consideration of pulverized coal for use in the malleable foundry. The figures that are given by most of the manufacturers of pulverizing equipment are not to be relied upon absolutely, and I have been anxious to get a figure which was authentic for a plant of moderate capacity.

F. WOLF: I can give you the cost on operating labor, motors, alterations, unloading, altering, handling, etc., on a plant which will turn out five tons of coal product. Not taking interest on investments, the cost is about $1.65 per ton of coal pulverized. This was taken over a period of years and an average gathered somewhere around 9,810,000 pounds; that is, pulverizing that amount of coal. The plant had been in service about a year when I started to gather this data. I might say that the cost of the plant was about $100,000, including buildings and all equipment. We are running one melting furnace and firing 250 horsepower Sterling boilers. We did at one time fire four of them.

W. R. BEAN: There is another question which relates to Mr. Lansing's discussion, oxidation lost in melting, the amount of carbon that is burned out during a heat.

W. ROMANOFF: The morning charge is about 3.30 to 3.40 per cent carbon; pig iron is hard to get by carbon analysis, but we aim to put in about 3.30 to 3.40 carbon in the morning and add about 3.20 carbon in the afternoon.

DAVID MACINTOSH: We have a small powdered coal plant at Easton, one of the smallest in the country, and I have trailed our loss, and I find that our loss in carbon is from 48 to 60 points with the holdback system on the furnace. I charge from about 3.12 to 3.20 per cent carbon. Our carbon loss is generally 48 to 60 points.

W. H. FITCH: This cost of $1.65 a ton for pulverizing coal I think does not answer all the question. For instance, if I hire a man to do a boy's work, it costs more than it should, but where a

plant is designed to do work and do it efficiently, that cost is very much lower, it might be 50 cents a ton. For instance, if you buy a plant that has a capacity of five tons an hour, or 120 tons of coal a day of 24 hours, and you only use about 20 tons of that capacity, you have to take labor, cost of investment and all that and divide that through the used tons, instead of what the plant is capable of, and always a manufacturer will pick out an installation that is very much larger than he needs. For that reason his cost is not comparable with one which will fill the bill and which over a year's experience is proven to be sufficient for his needs. The first cost is kept down and the corresponding cost of pulverizing coal is kept down. Only recently we have had prospective customers admit that they always thought it was necessary to have two five-ton pulverizers. Now they say they are satisfied they only need one. With a reliable installation and a few repair parts, your plant can be operated continuously and without interruption to practice, and that is a good point, I think.

F. L. WOLF: This plant that we are speaking of, of course, is not run to capacity, it is probably run six to eight hours a day, but I recently checked with Mr. Harrington, of the Hunt-Spiller Company, and we checked pretty near on all items, and the same on the operating cost. I might say that the power alone runs about 83 cents a ton. I have heard of 50-cent power, but have never been able to check up anybody.

W. H. FITCH: I would like to answer Mr. Wolf's question in a few words and say that we have an example of what I am trying to bring out right here in the Lakeside plant in Milwaukee. They have eight Fuller mills in their pulverizing department, with continuous operation, and I think they have about 750 tons of coal a day, which is probably 70 per cent of the capacity of those mills, and in that plant, over a period of years as published in the report at great length in the Edison Society's papers, 26 cents a ton was the cost of preparing coal, including all labor, material for repairs, care, etc. Just to show you how far we are off on that subject, as information given by us in advance, we set 28 cents a ton, so that we are two cents too generous. That is, for your general information on that subject, the best we can give you.

W. R. BEAN: In connection with Mr. Fitch's remarks, I would like to ask the question as to whether he would advise a malleable foundry having the need, we will say, for 30 tons of coal per day, to put in a two-ton installation and operate that 15 hours a day, 16 hours a day, or put in a five-ton installation and operate it 6 hours a day, which is approximately, as I recall, the basis of the Ohio Brass. You can save something on your investment by putting in the smaller plant, but your labor runs up if you operate that plant for longer than is required with the larger capacity machine. Personally I think that the malleable foundry cannot expect to get the pulverizing cost

that is obtained in a plant such as is referred to here, a power plant operating and using coal 24 hours a day. My connection with pulverized coal in the malleable furnace has covered a period of just ten years this summer. The first heats taken in the air furnace with pulverized coal, 30 odd in number, were taken at the Deering Works of the International Harvester Company in the summer of 1914 under my supervision. I am interested personally in the subject perhaps as much as anyone. I feel that pulverized coal has a place in the malleable foundry for furnace operation and annealing. I feel, however, that with the very high cost of installation, it is necessary for the foundryman to consider very carefully the items of interest and depreciation and actual cost of operation under the conditions that have to be met in the malleable foundry as we have it. I purposely brought up this question of the pulverizing cost, because I have not found that the small plant can come down to the figures that are generally given as representing the cost of pulverization.

A. J. GRINDLE: I agree with Mr. Bean on everything he says; you cannot expect any malleable foundry in the United States to burn as much coal as the Lakeside Plant, and therefore you cannot use the installation there as a pulverizing cost. We find the pulverizing cost in the ordinary malleable foundry runs from about a dollar a ton in the big installations up to $2.00 a ton for the smaller plants. The figures of the Hunt-Spiller Corporation in Boston are based on a new plant. If they are $1.65 a ton, I think they are about right; that is not operating at full capacity. In talking to malleable men, most of them want to operate their plants eight hours a day. If they run two shifts, that cuts their operating cost down. Of course, the installation does cost more if you put in a plant twice as large as necessary. I would like to say a little more on the individual pulverizer. Twenty-eight cents a ton for coal at the furnace with an individual pulverizer could not be compared with complete central station installation, because there is no line equipment to take into consideration. That all costs money, and it costs money to operate and costs money for repairs.

W. C. MCMAHON: Manufacturers of pulverizing machines all claim that there is a great reduction if you use a smaller percentage of pig iron. I think that is what Mr. Lansing was trying to get at.

J. H. LANSING: Yes, we found that.

Report of Committee on Malleable Iron Castings

To the Members of the American Foundrymen's Association:

You are probably all aware that a joint meeting of the A. F. A. Malleable Iron Committee and A. S. T. M. Committee A-7 was held last June at Atlantic City at the time of the summer meeting of the A. S. T. M. At that meeting the matter of including a yield point provision in the present specification was quite thoroughly ventilated. No decision, however, was reached as it was thought best to defer action in order to allow a more thorough discussion by a larger number of the two committees, particularly as it was the belief at the time that inasmuch as the A. F. A. convention was shortly to be held in this city the occasion would afford opportunity for another joint meeting and a larger attendance. However, a canvas of the situation prior to this convention and during the past several days made it plain that this could not be practically accomplished owing to various causes, among which were conflicts and the fact that it seemed impossible to set a time mutually convenient for the majority of the members present some of whom could not remain for the full period of the convention.

It appears practically certain that at the next joint meeting, a resolution with the end in view of introducing a yield point requirement will again be offered and probably passed. At the June meeting it was again suggested that various specifications be made for different grades of malleable iron, details of which were to be considered at a following meeting.

Resolutions of deep regret were passed in connection with the death of Chairman Diller.

The present plan of the Chairman is to suggest a joint meeting several months before the next A. S. T. M. summer meeting in order that the matters referred to in the foregoing can be fully considered prior to that meeting.

Respectfully submitted,

ENRIQUE TOUCEDA, *Chairman*

Heat Treatment of Steel Valve Castings in the Electric Furnace

By V. T. Malcolm and A. Sproat, Indian Orchard, Mass.

The main object of the heat treatment of large castings for valves is to attain absolute temperature control and uniformity of temperature throughout the charge of castings as serious defects may result from lack of uniformity in heat treating. These defects may take the form of cracks, hard and soft spots, etc. Uniformity of treatment is of course dependent upon temperature control, and the time element.

Uniform Heat Obtained With Electric Furnace

Experience has shown that, where possible, it is advisable to maintain a uniform standard treatment, therefore being better enabled to operate the furnaces on a schedule which has a definite arrangement. By such an arrangement shop complaints and much lost time can be eliminated.

With this object in mind we installed the car type of electric heat treating furnaces, for the heat treatment of steel castings for valves, and after three years of operation they have proved to be a decided success.

Not many years ago electric furnaces for heat treatment were considered mostly laboratory devices to be used in the laboratory because of the accurate results obtained.

Heat application in furnaces in this country has largely been the composite result of promotion and advertising rather than engineering. Many manufacturers, engineers and executives are unfamiliar with the possible economies of electric heating, and drop it from further consideration on the theory that its use is both expensive and impracticable. Experience, however, has shown that the electric heat treating furnace, when all things are taken into consideration, has the advantage of decreased main-

tenance, cost of upkeep, a simpler and more definite control which, of course, gives greater uniformity in heat treatment and hence uniformity in the product.

Continuous Operation Possible

Electric heat treating furnaces in our works have been operating twenty-four hours per day, seven days a week, at 1,700 degrees Fahr. for 25 months with no interruption to service ex-

FIG. 1—ELECTRIC HEAT TREATING FURNACES. FURNACE NO. 2, ON THE RIGHT, IS IN COURSE OF CONSTRUCTION AND THE RESISTOR IS NOT IN PLACE

cept minor repairs in the doors, cars and sand seals. These repairs, however, did not necessitate shutting down the furnace.

Some of the striking features of electric heat treating furnace operations may be summed up as follows:

The heat is released at various points, hence uniformity of temperature.

Heat generated balanced against heat absorbed.

Heat generated in an inactive or dead atmosphere with no contamination of the charge.

No localized high temperatures.

Small heating chamber, no combustion chamber necessary.

No hot gases leaving the furnace except through vents.

Automatic temperature control, abolishing the human element.

Heat transmitted by radiation.

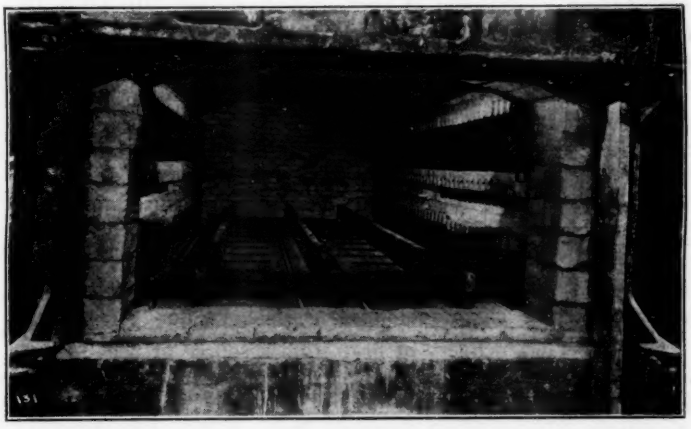

FIG. 2—CLOSE-UP VIEW OF ELECTRIC FURNACE SHOWING RESISTORS AND HANGARS

Complete saturation of charge without surface overheating due to perfect automatic control.

Ni-Chrome Ribbon Resistors Used

The electric furnaces used at our works are of the ni-chrome ribbon resistor type, which consist essentially of a strongly fabricated shell with a heavy thickness of high grade insulating brick laid in several courses, with all joints broken. The heating element consists of ni-chrome ribbon which is exceptionally strong and rugged. These ribbon elements are distributed over the inside walls on insulating hangar brick which are built into the fire brick lining. A single length of ribbon constitutes each

phase. The phase terminals are brought through the furnace walls in close fitting insulated bushings to connecting blocks on the outside of the furnace wall.

This type of furnace is in our opinion the most simple in construction of any furnace we know, as it contains no combustion chamber, flues, portholes, false bottoms or double arches. The hearth, walls and roof, all being solid, can be insulated to the best advantage to prevent loss of heat. Temperatures evolved, not being greater than 1,800 degrees Fahr., and the fire brick having a coefficient of expansion nearly zero, the result is a tight furnace in which all the mechanical strains are reduced to a minimum.

The furnace is equipped with seals that fit snugly into the sand container located on the side and edges of the car which carry the charge, and these sand seals form a tight joint and prevent loss of heat from the furnace in any way.

Furnaces of this type afford an atmosphere free from contaminating gases, and the penetration of the heat is even and thorough, without burning or cracking, for reason that the charge is heated by radiant heat, of uniform intensity in an unmuffled heating chamber. This unmuffled heating chamber lends itself to almost perfect delivery of heat from a source of heat to the work, and makes a perfect heat control by automatic means, promoting rapid and uniform heating.

Temperature Control Most Important

The temperature control is the most important feature and is operated by the "on and off" principle, that is, the power is cut off by automatic regulators when the temperature of the furnace reaches a predetermined "setting" and is again cut on when it falls below this setting. This operation is readily seen on the graphical chart, as the plotting is formed like a "saw-tooth" during the soaking period, or when automatic control is cutting "on and off."

The operation is accomplished by means of a thermo-couple located on the surface of the charge, and another one located at a point directly above the charge, these couples being connected to the recording potentiometers which actuate the automatic controllers. The reason for the use of two thermo-couples is to

enable us to be sure the furnace seals are tight, for a difference of more than 60 degrees Fahr. between the two readings during the soaking temperature immediately shows us that heat is escaping through the sand seals, which indicates that the sand seals have not been made correctly.

Operated by Automatic Control

The automatic control operation is vested in a potentiometer through which a high degree of sensitiveness is obtained. In the potentiometer the electro-motive force of the thermo-couple is measured by opposing it to a variable, but known electro-motive force, the condition of the balance being indicated by a sensitive galvanometer for a given increase or decrease in electro-motive force and can be much greater than that of a galvanometer used as a milliameter, since the latter must in its range of deflection measure the total electro-motive force of the thermo-couple, while the whole range of deflection of the potentiometer galvanometer can be utilized for registering the small amounts by which the thermo-couple electro-motive force momentarily differs from the opposed electro-motive force. The paper used in the graphical chart of the recording instrument is propelled forward by the same motor that is used for the potentiometer adjustment. The standard speed is three inches per hour. The recording controller, therefore, not only keeps the temperature of the furnace uniform, but also keeps an accurate graphical record of the temperature readings.

The temperature control of the electric furnace is unique in that the temperature of the actual charge is measured within the accuracy of the thermo-couple; this being due to the fact that the atmosphere in the furnace is "dead" and the charge brought to temperature by radiant heat. Therefore, by means of the automatic control the temperature distribution is uniform and the rate of heating and cooling controlled precisely by it. The heating cycle once established may be repeated, assuring absolute uniformity of product. The automatic control eliminates the human element, because when once adjusted to the desired temperature it will maintain it indefinitely.

As a safety device, there is located in the roof of the furnace, a fuse of a gold alloy which will melt if the temperature

exceeds 1,800 degrees Fahr., and by so doing automatically cuts off the current from the furnace and saves the resistor from burning out.

Sudden Cooling Should Be Avoided

The method of charging castings into the furnace and the manner of withdrawing them from the furnace will have a great bearing on the uniformity of the product; for instance, in transferring from the heating chamber to the cooling chamber if cold currents should strike the castings, a sudden cooling effect would take place setting up internal strains and hard spots which would be found difficult to machine.

In charging a heat, care should be taken to charge castings of nearly similar design and thickness of section, as castings of intricate design and small section deserve particular attention in charging, heating and withdrawing. When castings of this type are charged with heavy simple castings complications are likely to result, because if light and heavy castings are charged together the light castings will attain their temperature long before the heavy ones, which causes a loss by holding the furnace at high temperature while the heavy ones are being heated.

Very Little Scale on Annealed Castings

We have found with the use of the electric furnace that castings even when quenched from 1,700 degrees Fahr. in still air, show very little scaling and no deformation due to warping, even though we have treated very light castings.

Three methods of heat treatment are listed with their chemical composition and the physical properties obtained by each method.

Three Methods of Annealing

The first method was straight annealing in which the castings were heated to 1,600 degrees Fahr. for a period of three hours and allowed to cool to below 800 degrees Fahr. in the furnace. Table 1 gives results of this treatment.

The second method was to heat to 1,650 degrees Fahr. for two hours and to quench immediately in still air. This is known as the normalizing process and results are shown in Table 2

Table 1

Tensile Properties—Treatment 1

Test No.	Per Cent Carbon	Per Cent Manganese	Elastic Limit, Pounds per Square Inch	Tensile Strength, Pounds per Square Inch	Per Cent Elongation in 2 Inches	Per Cent Reduction in Area
251	0.28	0.652	39,000	69,600	24.2	32.5
252	0.29	0.660	39,900	69,950	25.1	33.5
253	0.30	0.690	41,500	72,470	23.4	31.6
254	0.28	0.740	40,600	71,460	25.5	34.4
255	0.29	0.710	42,300	74,600	24.0	32.7
256	0.27	0.730	42,700	76,500	23.6	30.3
257	0.30	0.718	43,000	75,400	23.2	32.6

Table 2

Tensile Properties—Treatment 2

Test No.	Per Cent Carbon	Per Cent Manganese	Elastic Limit, Pounds per Square Inch	Tensile Strength, Pounds per Square Inch	Per Cent Elongation in 2 Inches	Per Cent Reduction in Area
2-611	0.27	0.71	47,000	83,900	22.6	34.8
2-612	0.29	0.743	49,300	86,450	22.0	33.7
2-613	0.32	0.697	51,000	87,600	23.9	34.1
2-614	0.31	0.717	50,600	88,420	22.7	32.7
2-615	0.30	0.686	48,700	81,620	22.9	35.8
2-616	0.29	0.762	47,800	84,580	23.6	36.9
2-617	0.31	0.734	48,250	82,630	23.8	37.0

Table 3

Tensile Properties—Treatment 3

Test No.	Per Cent Carbon	Per Cent Manganese	Elastic Limit, Pounds per Square Inch	Tensile Strength, Pounds per Square Inch	Per Cent Elongation in 2 Inches	Per Cent Reduction in Area
3-717	0.34	0.777	53,400	94,200	24.1	42.0
3-721	0.35	0.796	51,800	87,150	25.0	41.3
3-722	0.35	0.805	53,000	98,550	24.0	42.2
3-723	0.32	0.814	56,300	97,000	26.0	43.3
3-727	0.34	0.829	54,900	94,650	28.4	47.1
3-731	0.33	0.721	58,150	96,800	25.5	42.5
3-739	0.32	0.784	52,550	90,650	26.0	45.5

Table 4

Charpy Impact Values

Heat Treatment No. I Average Foot Pounds..... 8.62
Heat Treatment No. II Average Foot Pounds.....14.41
Heat Treatment No. III Average Foot Pounds.....13.90
Fractures on all bars were fine silky crystalline.

The third method we may call the modified normalizing process and by this process remarkable physical properties have been obtained.

Castings are heated to 1,700 to 1,725 degrees Fahr. for a period of one hour and immediately withdrawn from the furnace under cover of a protecting metal box. This allows for an intermediate cooling range between annealing and normalizing, and eliminates the large grain size due to annealing, and imparts to the castings the fine grain size of normalized castings at the

same time giving splendid ductility, not usually found in normalized castings. Table 3 shows physical properties due to this treatment.

Use Shield to Protect Castings on Cooling

Great care must be taken in the cooling operation to be sure that castings are thoroughly surrounded by the shield so that air currents blowing through the shop do not come in contact with hot steel.

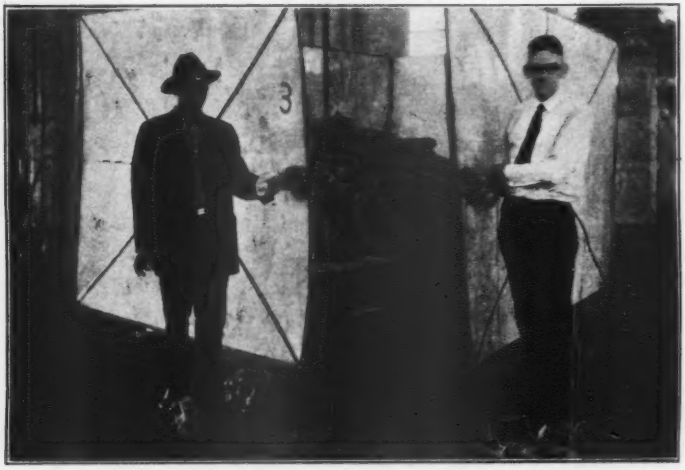

FIG. 3—VIEW OF METAL PROTECTING BOX USED IN NO. 3 METHOD OF TREATING CASTINGS

It might be well to state that all castings are tested, after finished machined and assembled, at not less than 1,000 pounds per square inch hydrostatic pressure and in some cases up to 2,500 pounds pressure with kerosene, which is one of the most searching liquids we know.

As a matter of interest it may be stated that numerous castings have been tested by heating to a temperature of 400 degrees Fahr. for a period of several hours and without releasing the heat, to immediately pump cold water into them at pressure of

1,000 pounds per square inch. This, in our opinion, is a very severe test, and certainly is a criterion of the heat treatment.

Conclusion

In conclusion, it may be stated that steel castings, properly heat treated, will possess physical characteristics comparable to forgings. Great stress, however, must be laid on the melting of the steel, for the reason that defects are more pronounced in castings, and foreign inclusions have a great effect upon their strength, due to the segregation of ferrite. The rate of cooling after pouring and the pouring temperature also have marked effect upon the castings on account of the tendency toward the formation of dendrites.

The authors wish to express their thanks to J. Juppenlatz for his work in making the tests which are recorded in the tables.

Discussion—Heat Treatment of Steel Valve Castings in the Electric Furnace

A. W. LORENZ: I would like to ask the writer a question. What is the cost of replacing the resistor elements? Do you have to replace them often, and what is the average cost? Can you give us an idea of the number of kilowatt hours consumed per ton of metal?

V. T. MALCOLM: The cost of replacing,—first, the cost of the resistor elements I am sorry, Mr. Lorenz, I don't know. The replacement, I think we have only replaced a resistor element in one of our furnaces. That furnace has been operated for 25 months and the resistor element has only been replaced once. The other one is still in operation as originally installed. Approximately; about 100 kilowatt hours are consumed per ton of metal.

A. W. LORENZ: How long does it take to heat up your charge, and what is the weight of the charge?

V. T. MALCOLM: The weight of the charge is five tons. It takes from 1,000 degrees to 1,725, it takes eight hours. As the castings come out the furnace drops to 1,000 degrees when the new load is placed in.

A. W. LORENZ: Then you hold one hour?

V. T. MALCOLM: Including the one hour; eight hours is the actual time.

A. W. LORENZ: I might ask another question, although I believe the paper really gives an idea about it. That is, the comparison in

repairs over an oil-fired furnace, comparing an oil-fired with an electric fired. I gather from the paper that you have very few repairs to make.

V. T. MALCOLM: The only repairs to the electric furnace, so far as we have come in contact with them, are repairs to the cars and the sand seals. The sand seals are the poorest feature about the electric furnace. Probably all understand how the sand seals work. In Fig. 1 you will note at the right and left corners of the cars located in the furnace you will see a sort of a slide. There is a metal shield that drops down here and as the car is pushed into the furnace, it goes through like that. This entire area here is filled with sand, and this steel pushes right into the sand and forms the seal, so that the furnace is tight right straight across there and nothing comes out. The car bottom lays under and this seal blocks everything off. Now there is the main trouble with the electric furnace, is the upkeep of those seals and the knocking off of the edges of them and the breaking of this plate. These plates are made in sections, not one full plate. Here is the main trouble. The workmen are inclined to be a little careless occasionally with not getting the seals set properly. But as I noted in the paper, you can immediately, by the use of the pyrometer, detect when the sand seals have been made incorrectly, for the reason that the couple located on the work and the couple directly over the resistor wire will show a difference of probably 150 to 200 degrees, just according to how much heat is escaping from the bottom of the furnace.

A. W. LORENZ: Do you know whether there is any saving, or how much saving you effect in chipping cost on account of the lesser amount of scale?

V. T. MALCOLM: Well, we have made up a chart showing the amount of scale that was given for a given size casting in the electric furnace. We find, however, that the scale is so slight that it is hardly much over .06 or .07 of an inch in thickness, hardly noticeable. It is practically unnecessary to clean the scale off the castings.

A. W. LORENZ: That is the point I wanted to get at, whether it was necessary to do any sand blasting to clean the scale off.

V. T. MALCOLM: No, in most cases it is not necessary to clean the scale off. They scale very little.

The Microscope as a Control Instrument in Annealing Steel Castings

By J. Fletcher Harper and H. J. Stein, Milwaukee, Wis.

This article is a plea for the wider use of the microscope as a control instrument in the annealing of steel castings, for it has been found that when the microstructure is satisfactory the physical tensile properties of the castings more than meet the specifications. It is a description of the method used by the Allis-Chalmers Manufacturing Co in the annealing of medium carbon steel castings.

In order to understand fully the process of annealing, it will be necessary to state briefly the now accepted explanation of the solidification of medium carbon steel.[1]

Explanation of the Solidification of Medium Carbon Steels

Steel above a certain temperature, which is from about 2732 degrees Fahr. (1500 degrees Cent.) to 2192 degrees Fahr. (1200 degrees Cent.), dependent upon the composition, is in the molten state. On cooling below this temperature, solidification begins about various centers which are at lowest temperature. This results in formation of crystal skeletons.[2] The skeletons rapidly develop branches which become more and more coated with crystallizing matter until the whole resembles a tree. It is from this action that the term dendrite or tree-like is derived. The action is similar to the formation of rock candy in a sugar solution.

The formation of a single crystal in steel, however, is very rare; so we must consider that a number of these dendrites are forming until they interlock and the whole material is solid.

This solidifying of steel from the molten to the solid state is called the primary crystallization, and it is during this stage

[1]The little understood Delta Gamma transformation has been omitted.

[2]*The Crystallization of Iron and Its Alloys* by Albert Sauveur, Transactions of American Society for Steel Treating, July, 1923.
The Crystallization of Metals by Col. N. T. Belaiew.

that any non-metallic particles are entrapped between the branches of the dendrites.

If the number of non-metallic particles is great and the rate of passage from the liquid to the solid is relatively slow, the formation of dendrites is slow and these non-metallic particles are trapped in streaks or lines between the dendritic branches. It is practically impossible to move non-metallic inclusions by heat treatment short of fusion.

The above explanation of the mechanism of primary crystallization will explain the weakness at corners in dirty steel castings. The dendritic formations proceeding from two surfaces force the non-metallics in the molten metal to their extremities, until when the dendrites interlock a plane of inclusions is formed.

While the metal has passed from the liquid to the solid state and now has shape, this metal (with the exception of the non-metallic particles) must be considered as having a crystal grain but not having any individual constituents. This condition is known as a solid solution and the steel is said to be austenitic.

As the temperature of the steel, varying from about 1652 degrees Fahr. (900 degrees Cent.) to 1274 degrees Fahr. (690 degrees Cent.), dependent upon the composition, falls, another crystallization takes place. This is termed the secondary crystallization. It proceeds, in steel below .85 per cent carbon, by ferrite or iron content freezing out, until a temperature of approximately 1274 degrees Fahr. (690 degrees Cent.) is reached. At this temperature the remainder, or the eutectoid, forms. The eutectoid is called pearlite and is made up of alternate layers of ferrite and cementite which has a composition of approximately .85 per cent carbon.

Secondary Crystallization Proceeds in Three Ways

The secondary crystallization can be considered to proceed in three ways which cause three distinct structures in cast steel.

First, if the passage of the steel from the austenitic state through the critical temperature is slow and the size of the crystals not too great, the ferrite will form as an envelope or net work about the austenitic grains, leaving the pearlite as the cell or inner structure.

If the interval of secondary crystallization is covered rapidly, the ferrite grains will separate throughout the metal and will be parallel to the crystallographic planes of the austenitic crystallization. This results in the well known Widmansträtten structure.

When the period of secondary crystallization is lacking, the proeutectoid element is thrown out parallel to the axis of the primary crystals. This formation is rare in steel, being usually in large crystals, but it is that generally found in semi-steel and white iron.

Process of Annealing Alters Secondary Crystallization

The primary crystallization formed and the non-metallic inclusions grouped at the time of solidification are not affected by any of the commercial forms of heat treating. Therefore, the process of annealing medium carbon steels becomes the altering of the secondary crystallization. This is done by reducing the size of the two constituents, ferrite and pearlite, and the uniform distribution of one constituent in respect to the other.

The reason for this redistribution is because the large grains, the splines, or the needle-like Widmänstratten structure of the cast metal offer very little resistance to the path of fracture.

Due to the manner of cooling from the austenitic range at the time of casting, the concentrations of the various elements are very non-uniform. It, therefore, becomes necessary to heat above austenitic-ferrite (Ac_3) thermal critical temperature for resolution of the elements ferrite and pearlite.

The higher the temperature above this point of solution, the more rapid is the equalization of the concentration. At the same time the higher the temperature, the larger is the grain growth; so that a limitation is placed upon this equalization by increasing the temperature. There is also the additional disadvantage of an approximation of the three types of secondary crystallization again forming on cooling.

The ideal way to equalize the concentration would be by prolonged heating at just above the critical temperature. However, in large castings this time requirement is not commercially practical; so that an intermediate course is found to be best. This consists of a moderate time of holding at a temperature 100 degrees Fahr. to 200 degrees Fahr. above the critical tempera-

ture, followed by as rapid cooling to well below the critical temperature as the variations in section of casting will allow. This rapid cooling is to retain the constituents in as unform concentration as possible and to prevent their segregation during the interval of cooling. This treatment should be followed by a reheating to just above the critical temperature to reduce the grain size.

An additional treatment which greatly increases the ductility was described by R. S. MacPherran and one of the authors in a paper,[3] before the American Society for Steel Treating.

Spheroidizing of the Cementite of the Pearlitic Constituent Increases Ductility

This treatment has for its purpose the spheroidizing of the cementite of the pearlitic constituent. It was found that by reheating to a temperature at or slightly below that at which the eutectoid (pearlite) forms, for moderate lengths of time (five to eight hours), that the cementite of the pearlite spheroidized.

This spheroidizing treatment causes the sections of the laminar cementite of the pearlite to be dissolved in the ferrite of the pearlite. The remaining portions of the cementite coalesce by surface tension causing globules of cementite to be formed. This form of the pearlite increases the obstructions to the path of rupture, reduces the areas of the brittle cementite, and hence increases the ductility.

In taking tests of cast steel where the casting is of large section the test bar to be representative should be drilled from the body of the casting. The reason for this is that the small section of a coupon bar, due to its casting and heat treating conditions, does not represent the casting.

Explanation of Photomicrographs

The photomicrographs Series 1 (Nos. 1, 2, 3) illustrate this condition. These photomicrographs refer to a uniform section steel casting, weighing about 1000 pounds. Photomicrograph 1 is of a coupon test bar (1x1x6 inches cast on the casting) after an anneal of 1600 degrees Fahr., held for eight hours. Photomicrograph 2 is taken from a section sawed from the casting it-

[3] *Spheroidization of Cementite in Hypocutectoid Steels*, by R. S. MacPherran and J. F. Harper, Sept., 1923. Transactions Amer. Society for Steel Treating.

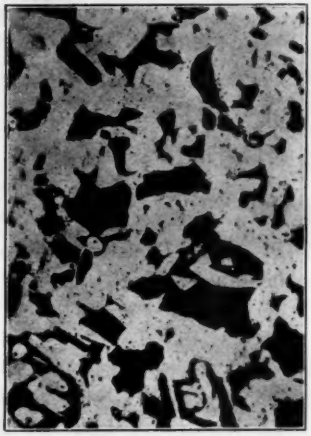

FIG. 1—SERIES I, PHOTOMICROGRAPH NO. 1

Test taken from Coupon Test bar of 1000-pound steel casting.—Treatment, 1600 degrees Fahr., maintained 8 hours. Cooled in furnace.—Car., 0.28 per cent; mang., 0.60 per cent; phos., 0.035 per cent; sul., 0.044 per cent; sil., 0.29 per cent.—Yield point, 37700 pounds; ultimate strength, 71300 pounds; per cent elongation, 20; reduction of area, 28 per cent.

FIG. 2—SERIES II, PHOTOMICROGRAPH NO. 2

Micrograph specimen taken from casting itself.—Same casting as shown in Test Bar Photomicrograph No. 1.—No additional treatment.

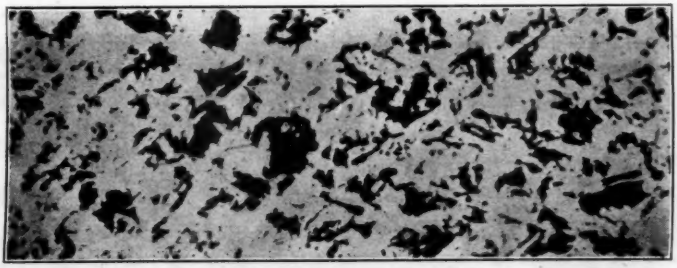

FIG. 3—SERIES I, PHOTOMICROGRAPH NO. 3

Test taken from 1000-pound casting after treatment given of 1550 degrees Fahr., maintained for 2 hours, quenched in water to approximately 1200 degrees Fahr., reheated to 1525 degrees Fahr., maintained for 4 hours, cool in furnace.—Yield point, 37900 pounds; ultimate strength, 66850 pounds; elongation, 30 per cent; reduction of area, 45 per cent.

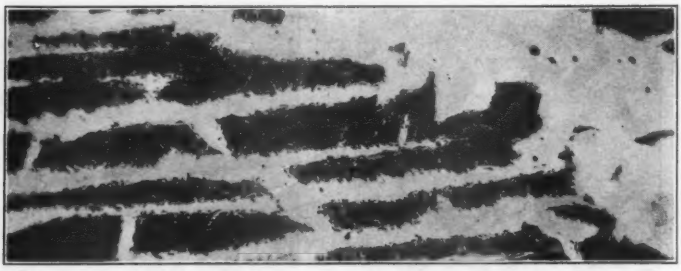

FIG. 4—SERIES II, PHOTOMICROGRAPH NO. 4

20,000-pound steel casting as cast.—Car., 0.28 per cent; mang., 0.67 per cent; phos., 0.034 per cent; sul., 0.040 per cent; sil., 0.310 per cent.

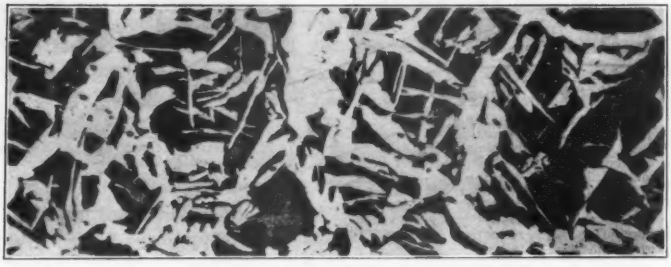

FIG. 5—SERIES II, PHOTOMICROGRAPH NO. 5

20,000-pound steel casting, same as shown in Photomicrograph No. 4, after heating to 1750 degrees Fahr., maintained for 15 hours, and air cooling.

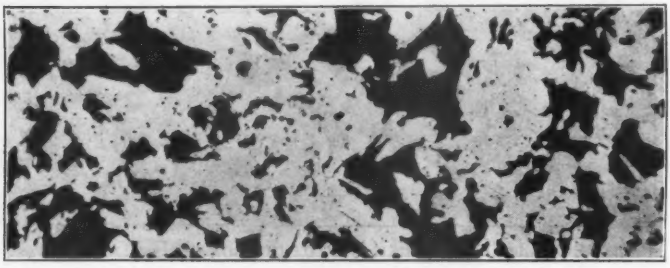

FIG. 6—SERIES II, PHOTOMICROGRAPH NO. 6

20,000-pound steel casting after additional treatment of 1550 degrees Fahr., maintained for 24 hours, then cooled in furnace.—Yield point, 43700 pounds; ultimate strength, 74900 pounds; per cent elongation, 30; per cent reduction of area, 50.

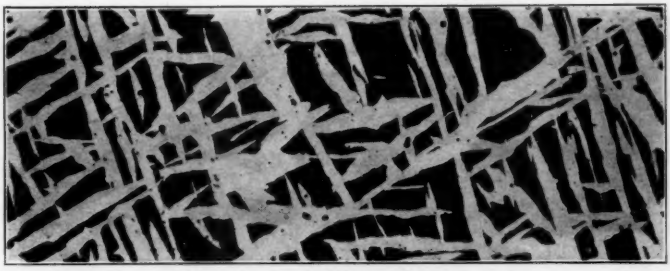

FIG. 7—SERIES III, PHOTOMICROGRAPH NO. 7

Interior of one grain of 5¼ pounds steel casting as cast.

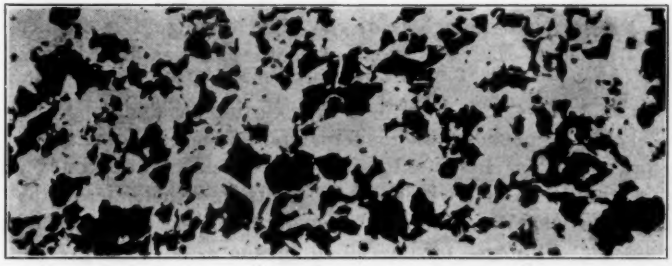

FIG. 8—SERIES III, PHOTOMICROGRAPH NO. 8

5¼ pounds steel casting, as shown in Photomicrograph No. 7, after heating to 1550 degrees Fahr., maintained for 2 hours, cooled in the furnace.

FIG. 9—SERIES IV, PHOTOMICROGRAPH NO. 9

12000 pounds steel casting as cast.—Car., 0.31 per cent; mang., 0.71 per cent; phos., 0.034 per cent; sul., 0.039 per cent; sil., 0.29 per cent.

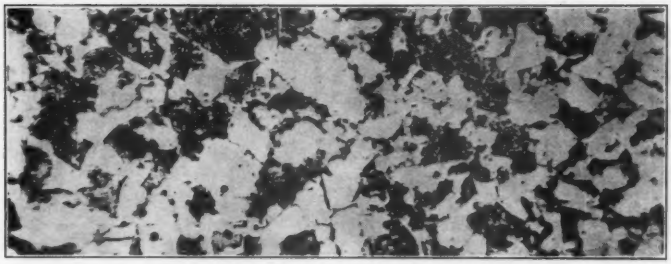

FIG. 10—SERIES IV, PHOTOMICROGRAPH NO. 10

12000-pound steel casting.—Yield point, 36500 pounds; ultimate strength, 70000 pounds; per cent elongation, 30.5; per cent reduction of area, 50.—Treatment, 1625 degrees Fahr., maintained 10 hours, cooled in air to 800 degrees Fahr., reheated to 1550 degrees Fahr., maintained for 10 hours; cooled in furnace to 800 degrees Fahr., reheated to 1290 degrees Fahr., maintained for 3 hours, air cooled.

self. Photomicrograph 3 is of the same casting after further heat treatment. This specimen and tensile bar was drilled from the casting.

Series 2 (Nos. 4, 5, 6) is of a large casting weighing approximately 20,000 pounds. Photomicrograph 4 is taken from casting before annealing. It shows the ferrite of one edge of a secondary grain and ferrite set within the grain itself. Photomicrograph 5 is taken after the treatment to equalize the concentration and shows the entrapped ferrite caused by the rapid cooling from the high temperature. Photomicrograph 6 is taken after the reheating to just above the critical temperature.

The casting shown in Series 3 (Nos. 7, 8) is very small, being 1¾x3½x3¾ inches and weighing 5¾ pounds. Photomicrograph 7 is the interior of one of the grains in the cast condition. It plainly shows the ferrite entrapped during the secondary crystallization within the grain in the characteristic Widmänstratten structure. Photomicrograph 8 shows, because of the size of the piece, the complete breaking up of this structure with the simple treatment.

Series 4 (9, 10, 11) is taken of section drilled from a steel casting weighing approximately 12,000 pounds. Photomicrograph 9 is of the material as cast. Photomicrograph 10 is taken after the triple treatment and the ductility is found to be exceptionally great. Photomicrograph 11 is an additional view of a portion of the section shown in number 10, but taken at 1000

FIG. 11—SERIES IV, PHOTOMICROGRAPH NO. 11

12000 pounds steel casting—Same as Photomicrograph No. 10—This view is taken at 1000x magnification and shows the spheroldized cementite of the pearlitic constituent.

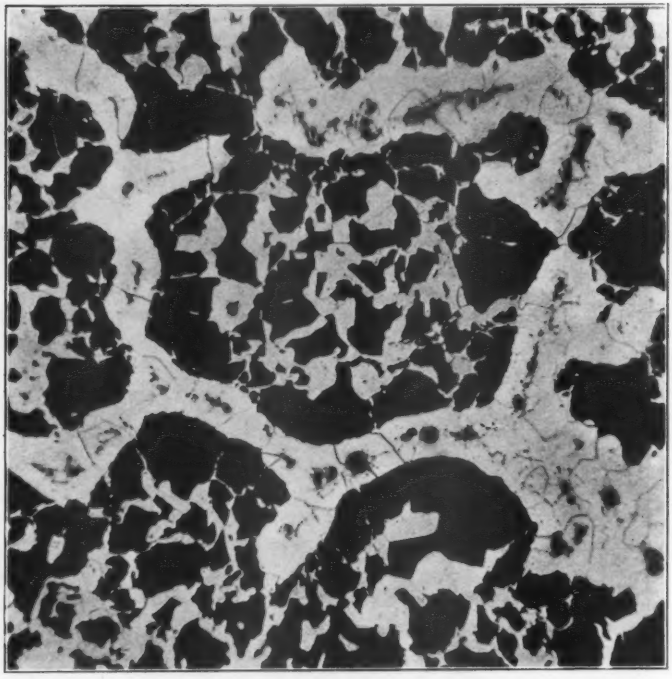

FIG. 12—PHOTOMICROGRAPH NO. 12

Non-metallic inclusions outlining dendritic crystallization—Yield point, 39550 pounds; ultimate strength, 75950 pounds; per cent elongation, 18; per cent reduction of area, 30.

diameter magnifications. This view shows how the cementite of the pearlitic constituent has been spheroidized, which accounts for the great ductility.

Photomicrograph 12 shows the slag streaks which are entrapped between branches of the dendrites in the primary crystallization and in this case completely outlining the dendritic formation. It is impossible to so equalize the concentration within the slag enclosed areas to properly anneal the steel. The slag areas are in streaks which cause the material to fail with low ductility.

All of the above photomicrographs were taken with a Leitz

microscope after etching the polished specimen with 5 per cent solution of picric acid in alcohol. Photomicrographs numbers 1 to 10 inclusive were taken at 100 diameter magnifications, using a 14 mm. achromatic objective and a No. 1 (2.6x) projection eyepiece with bellows extension of 62 cm. Photomicrograph number 11 is at 1000 diameter magnifications, using a 4 mm. aprochromatic objective, No. 3 (10x) projection eyepiece and 51½ cm. bellows extension.

Photomicrograph number 12 is at 100 diameter magnifications, using 24 mm. objective and 7½x eyepiece with a bellows extension of 43½ cm.

Summary

We have found that the microscope is a valuable control instrument in annealing steel castings.

It is our experience that when the microstructure is satisfactory the physical tensile tests will more than meet the specification.

Coupon test bars cast on a casting of heavier section than the test bar are not representative of either the microstructure or the physical tensile properties of the casting.

The true dendritic structure and the non-metallic inclusions in steel castings do not appear to be altered or moved by any commercial heat treatment.

Castings of light section can be satisfactorily treated by a simple anneal to just above the critical temperature.

Castings of heavy section and mass appear to require a more complicated heat treatment to commercially eliminate casting structure, give satisfactory microstructure, and get maximum ductility.

Spheroidization of the lamellar cementite of the pearlitic constituent greatly increases the ductility of the material.

In conclusion we wish to acknowledge the assistance of H. Freeman and R. S. MacPherran in our experiments; and Rexford Krueger in preparing the photomicrographs.

Discussion—The Microscope as a Controlling Instrument in Annealing Steel Castings

JOHN H. HALL: I have had very little time to read this paper over. I read it on the train as I came out. I would like to ask one question which I don't see the reason for. At the top of the fourth page it says, "This rapid cooling is to retain the constituents in as uniform concentration as possible and to prevent their segregation during the interval of cooling," with which I heartily agree. "This treatment should be followed by a re-heating to just above the critical temperature to reduce the grain size." I would like to know why that should be followed by a re-heating to above the critical temperature, because we have found in all our work that if you re-heat to above the critical temperature, you do what you don't want to do, you re-coarsen the microstructure, and I observe then that there is a third heating necessary for really good work, just below the critical range. My experience has been that if you cool rapidly, as is advocated in this paper, and get a fine microstructure, I never found it necessary for this triple heating. It seems to me that the reason for the third heating is that the second heating has been carried above the critical temperature, where it should not have been.

In the summary, "Castings of light section can be satisfactorily treated by a simple anneal to just above the critical temperature," and the photograph given, if I am not mistaken, is Figure 8. Well, that is a satisfactory job for plain, old-fashioned annealing, but for a really good heat treatment and a really fine set of physical properties, a simple anneal to just above the critical temperature, giving a microstructure like figure 8, is very far from satisfactory. Much better can be done with the double treating.

I am very far from wanting to criticize this paper adversely, because I think it is an admirable piece of work, calling attention very well indeed to the advantage of the microscope in the heat treatment of castings, but on a hasty reading, I could not see the use for that triple treatment when the same thing can be done in two treatments, and I hated to call Fig. 8 a really satisfactory microstructure for a light casting.

H. J. STEIN: I might mention the fact that this raising the temperature to slightly above the critical is due to the mass. Understand, these are all large castings, except that one section that we treated here, and it is due to the mass and the lag of the temperature, etc., that brings about this change. The third one of the triple treatment is given to bring aboutu the cementite in the spheroidized form, which in our results

has greatly increased our ductility without materially affecting the elastic limits.

A. W. LORENZ: I was interested in this paper because it deals with the annealing of large castings. Now, I think that when the proposed specifications of the A. S. T. M. were put forward, and which, of course, are being sanctioned by the Foundrymen's Association, that they deal mainly with the annealing of small castings. Those specifications were drawn up quite generally around the results obtained on test bars of about one inch cross section. Now, this paper deals with large castings, castings from ten to twenty thousand pounds. I think it shows you very plainly that you cannot treat them as you would an ordinary test bar, and I can see the reason for those treatments. They have to go to a very high temperature to reach the center of the casting and refine that, because the structure is very porous. Then, having refined the center to a certain degree, they have to still get a smaller grain size, which necessitates the second treatment to 1350, after which they give a third treatment. I think it is well worth while to consider that large castings cannot be treated the same as small ones.

CHAIRMAN A. H. JAMESON: As to the way the A. S. T. M. specifications were drawn, the chairman's recollection of it was that the question of the mass of the casting was rather taken into consideration in the drawing of these specifications. The question of the length of time at which the castings are going to be held at a certain temperaature is rather the answer to the question of the mass, is it not?

H. J. STEIN: The length of time at which these castings were held was derived merely from past performance. I think that that will answer the question.

W. J. PRIESTLY: Substantiating what the author of this paper has shown in the triple treatment, we have seen cases recently where large castings, weighing anywhere from fifteen to twenty tons, would pass a satisfactory test from the coupons taken from the surface of the casting, but the double treatment would not meet the test when a test bar was taken in the interior of the casting, where it was about 12 to 18 inches thick. Bars taken out of the center of the casting and put under a microscope showed that the original ingotism was not broken up, and that the very high normalizing treatment was necessary in order to get the bars to pass the test. That high treatment was then followed by the lower treatment above the critical, followed by one just below.

CHAIRMAN A. H. JAMESON: If the Chair may himself enter into the discusion, that brings up the question in the fourth section of the summary in the paper, does it not, where it says, "The true dendritic structure and the non-metallic inclusions in steel castings do not appear to be altered or moved by any commercial heat treatment." That is, the dendritic structure you found in these large castings could be broken up somewhat by a high normalizing treatment, didn't you, Mr. Priestly?

That has been my own experience, and I should be interested to know the reason for the conclusion that you have given here, Mr. Stein.

H. J. STEIN: I think that is a little misunderstood. It is not the dendritic structure that is caused to be broken up, it is the structure of secondary crystallization.

D. J. KENNEDY: I would like to ask Mr. Stein if he has any data on the machining qualities of the spheroidizing of cementite.

H. J. STEIN: I haven't any data except just from the usual observation in the machine shop, showing that the casting appears to be much more uniform, that is, free of the hard and soft spots.

MEMBER: I would like to ask whether the same condition on heat treating couldn't be obtained in the first heating by holding them a longer period better than by heating two or three times. It sounds to me as though it is under-annealing on the first treatment; that the same results could be gotten by a longer treatment at the same temperature, about as high as the critical point.

H. J. STEIN: In our works the increased length of time of holding to bring about that change is not commercial.

M. L. FREY: Isn't there another side of that question, too, the fact that by repeated passages through the lower critical you will get out of the double or a treble treatment a much finer grain size and therefore a stronger casting than you will out of a single treatment for a long time a considerable distance above the normal critical line. It would seem to me that that would have some bearing on the advantage or disadvantage of a double or a triple heat treatment as compared to a single one.

E. F. CONE: I would like to ask whether photomicrograph No. 12 represents simply some off heat that they ran up against, or whether it is the result of some special treatment, by the addition of some alloy or something of that kind.

H. J. STEIN: This is the ordinary commercial carbon steel that I spoke about, except that it shows very unusual results. In one place I spoke about the non-metallic inclusions being bound in by the ferrite crystallizing and causing them to be held there.

E. F. CONE: The reason I asked that question, some years ago in some experience I had in this line, by the addition of a certain compound that was supposed to be very beneficial to steel castings—you would immediately get a structure like this, giving a metal which had no elongation, practically, or very poor, and very little reduction of area, and without that addition the other heat turned out all right. I wonder if you had given this somewhat the same treatment.

H. J. STEIN: As far as that is concerned, I don't think that this casting was poured in any special way or had any ingredients outside of the ordinary commercial casting.

X-Rays in the Foundry

By Ancel St. John, Ph. D., New York City

Foundrymen are beginning to realize that x-rays can help them make better castings. The interest they are showing in this new development makes it worth while to present a brief description of what x-rays are, how they are used for examining castings, and what they disclose, together with a consideration of the circumstances under which their use is justified.

Theoretical Introduction

According to accepted theory atoms are built up of electrically charged particles. A positively charged center called the nucleus, is surrounded by a number of negatively charged particles, called electrons. The electrons are believed to move in orbits forming a sort of miniature solar system about the nucleus. The mass and charge of the nucleus and the number of surrounding electrons are characteristic of each element and are nearly proportional to the atomic weight—actually to the atomic number,— but the electrons themselves are the same for all elements. In addition to their normal motions about the nucleus the electrons may vibrate in other ways if the atom is agitated, and in so doing set up electro-magnetic or "light" waves. The force attracting an electron to a nucleus decreases with increasing distance between them but increases with increasing charge on the nucleus. It may be shown that as this force increases the work required to agitate an electron and the frequency of the resulting vibrations both increase, very much as a short, stiff spring vibrates more rapidly than a long flexible one.

Ordinary light is produced when agitation of the atoms displaces one of the electrons forming the outer portion of the atom; x-rays arise when the inner electrons are displaced. This is usually accomplished by the impact of a free electron moving with sufficient speed to penetrate to the interior of the atom.

After such impact each displaced electron vibrates with a definite frequency depending upon the structure of the atom and the original position of the electron until the acquired energy is dissipated as radiation of the wave-length corresponding to that frequency. The x-rays given off in this manner have wave-lengths peculiar to the atom and are called the characteristic

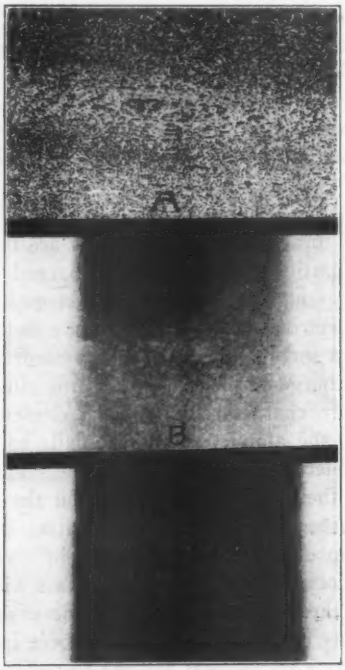

FIG. 1—A. SLAB OF "DIRTY" STEEL, HEAVILY ETCHED. B. RADIOGRAPH: ONE-HALF HOUR EXPOSURE WITH PROPER PENETRATING POWER. C. RADIOGRAPH: SHORT EXPOSURE WITH HIGH PENETRATING POWER; DEFECTS NOT SHOWN.

x-rays of that element. The stoppage of the free electrons also sets up a series of waves, known as the general or independent x-rays, of various wave-lengths exceeding a minimum determined by the speed of the impinging electrons.

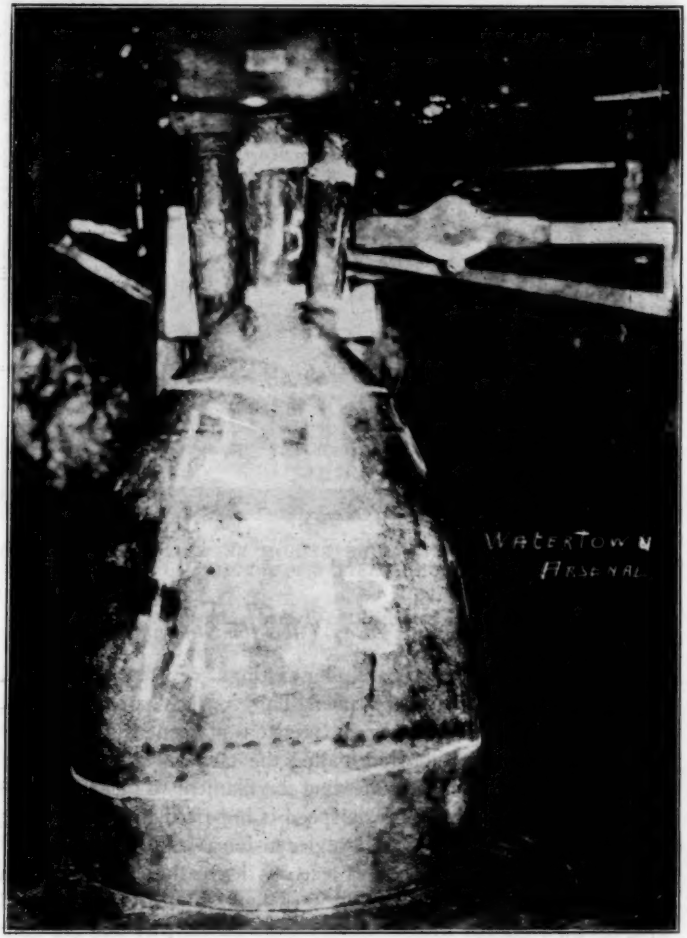

FIG. 2—400 POUND CASTING FOR BOMB, READY FOR RADIOGRAPHING.

FIG. 3—RADIOGRAPH OF POROUS REGION BETWEEN RISERS OF 400 POUND CASTING FOR BOMB

Use Coolidge Type of X-Ray Tube for Studying Castings

The x-rays used for examining castings are usually produced in the Coolidge type of x-ray tube. This consists of a glass bulb, highly evacuated, containing a tungsten filament and a heavy metal block, usually tungsten, called the target. The supply of free electrons is obtained by heating the filament to incandescence with an auxiliary current. The speed is imparted to the electrons by impressing the voltage of a high-tension transformer between this filament and the target. Electrons leave the filament when it is negative with respect to the target, travel to the target and give up their energy to it. As less than one-half of one per cent of the total energy thus imparted is converted into x-rays, the rest becoming heat, the target tends to become incandescent and to emit electrons on its own account. These would, in turn,

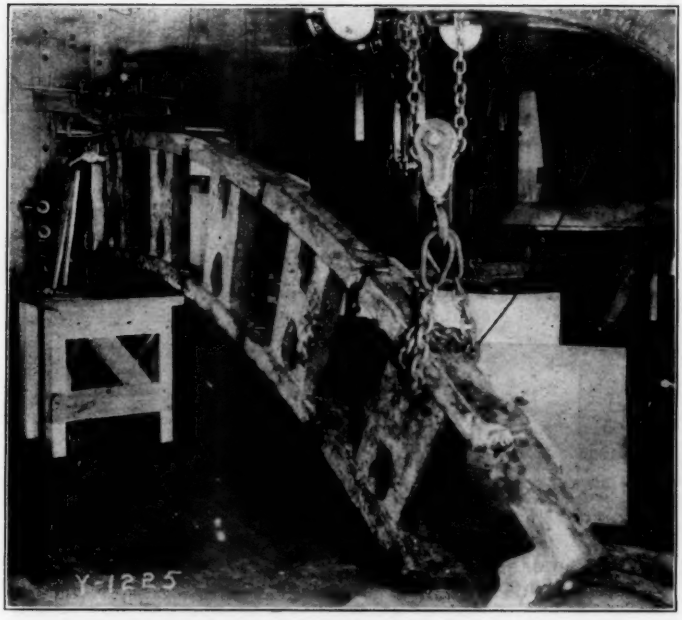

FIG. 4—CASTING FOR 16-INCH GUN MOUNTING READY FOR RADIOGRAPHING

travel to the filament when the target is negative with respect to it, giving rise to x-rays and additional heat in the filament. To prevent this a rotating switch is introduced into the high potential circuit and operated in such a way that the filament is always negative with respect to the target. The x-rays are then always produced at the target. The power of these tubes is limited by the rate at which the large quantity of heat can be dissipated from the target. To increase the power-capacity some tubes are made with arrangements for cooling the targets with water.

X-rays are only slightly visible to the human eye and produce such serious physiological consequences when they fall upon any part of the body frequently or for a long time that some other method than direct vision must be used for detecting them. When x-rays fall upon a substance part of their energy is ab-

FIG. 5—RADIOGRAPH OF PART OF CASTING FOR 16-INCH GUN MOUNTING, SHOWING LARGE INTERNAL CAVITIES

sorbed, part is scattered, and the balance passes through. When the incident x-rays are sufficiently short much of the absorbed energy is given off again as longer waves, known as secondary x-rays, characteristic of the absorbing substance, or in certain cases as visible light. Substances having this latter property are said to be fluorescent. In some cases part of the absorbed energy may cause physical or chemical transformations, such as ionizing a gas or activating a photographic emulsion.

The amount of the absorption and scattering depends upon the wave-length of the x-rays, upon the number and arrangement of the electrons in the absorbing atoms and upon the number of atoms of each kind which are encountered, but is entirely independent of the way the atoms are arranged. Expressed in another way, it depends somewhat upon the atomic weight of the target but principally upon the voltage across the tube and upon the composition, density, and thickness of the absorber. For a given voltage the absorption increases rapidly with the atomic

weight of the absorber; for a given absorber it decreases rapidly with increasing voltage.

Protection of Operator Necessary

In using x-rays it is necessary to protect the operators. This is done by surrounding the tube with lead of a thickness sufficient to absorb all but a negligible quantity of the rays. The most

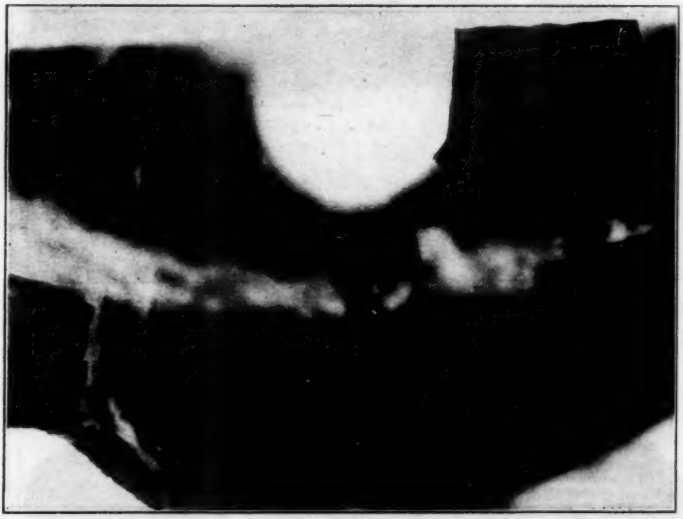

FIG. 6—RADIOGRAPH OF ANOTHER PORTION OF CASTINGS FOR 16-INCH GUN MOUNTING SHOWING A SERIES OF SMALL CAVITIES

powerful outfit now in use, situated at the Watertown Arsenal, works regularly at 195,000 volts. The tube is enclosed in a lead-walled room and the operators observe the tube through a lead periscope. The outfit at the Union Carbide and Carbon Research Laboratories, used by the writer, has been operated at 115,000 volts. The tube is enclosed in a large lead box one-quarter inch thick with an air blast or an oil bath for cooling the tube. The x-rays are allowed to come through openings in the box and after traversing the objects under examination are absorbed in heavy lead screens.

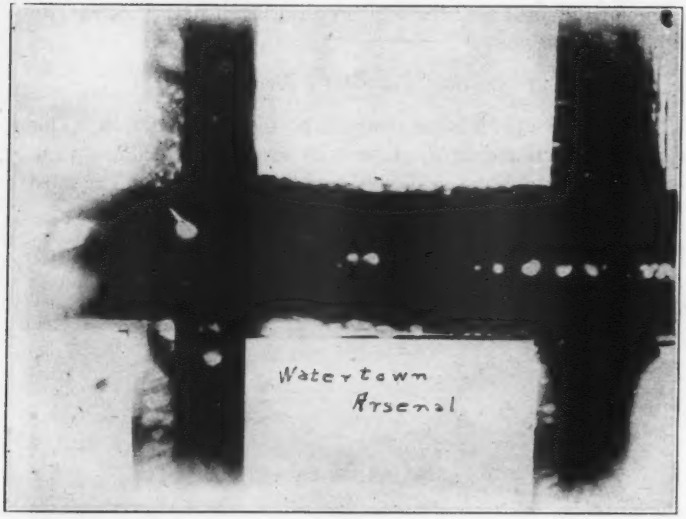

FIG. 7—RADIOGRAPH OF TRACTOR GROUSER SHOWING VERY POROUS STRUCTURE

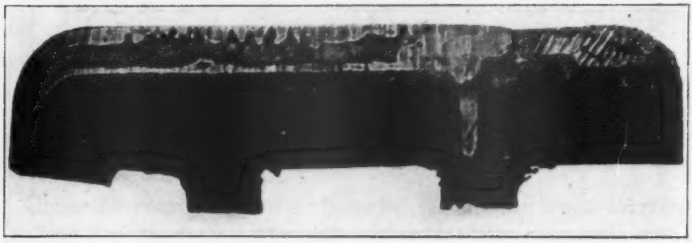

FIG. 8—SECTION THROUGH TRACTOR GROUSER

Method Used for Examining Metals

The method used for examining metals with x-rays is similar to that used by the surgeon in examining the human body except that since the materials under consideration are much less transparent to the rays a much greater penetration power is required.

The x-rays record a shadow picture on the fluorescent screen or photographic film, cavities, thin spots and foreign matter of atomic weight lower than that of the material as a whole appearing as regions of increased illumination, thick spots and foreign matter of higher atomic weight appearing as regions of decreased illumination.

In examining metals for hidden defects it is generally preferable to use the photographic method. Very weak rays which would not produce a visible effect on the fluorescent screen may be recorded on the film by a sufficiently long exposure. As the penetrating power of the rays increases the difference in density of the photographic negative due to a given difference in thickness of the material examined is reduced. Hence to detect small cavities or very slight differences in thickness it is desirable to use as low a penetrating power as possible. Experience has shown that an exposure of 150-200 milli-ampere-minutes, that is one-half hour with an ordinary tube, is reasonable. Using a penetrating power which will produce a satisfactory negative with this exposure cavities one-fiftieth the thickness of the specimen are disclosed. Thus with 195,000 volts cavities one-sixteenth inch thick have been found in steel castings three inches thick.

Explanation of Illustration

Through the courtesy of Dr. H. H. Lester, of the x-ray laboratory, and Colonel T. C. Dickson, the commanding officer at the Watertown Arsenal, a few illustrations of the use of x-rays in improving foundry procedure are presented. As originally designed the head of a demolition bomb had extensive cavities between the risers. Modification in the shape and distribution of risers eliminated these almost completely. Study of defects such as those illustrated, in the large distance ring castings, led to changes in design. Occasionally such rotten castings as the tractor grouser were detected, the cause found and eliminated.

X-rays can be of service to the foundryman in two ways. By co-operation between an x-ray laboratory, the designing room and the foundry the causes of many typical defects can be determined and often largely eliminated, so that the proportion of defective castings can be materially reduced. Where the annual production of a given type of casting is considerable a study of

this kind may be very much worth while. In cases where much expensive work is subsequently to be done on the casting it may be worth while to examine every piece and throw out those which are defective before any further money is expended on them. If human life is to be dependent on the soundness of the casting it is possible that 100 per cent inspection of this sort should be mandatory.

Discussion—X-Rays in the Foundry

CHAIRMAN J. H. HALL: Gentlemen, I am sure it has been a great privilege to have Dr. St. John with us, and I am sure his talk has been an extremely interesting one.

I would like to call the attention of the foundrymen to something that occurred to me when Dr. Lester of the Watertown Arsenal presented a paper along this line to the Iron & Steel Institute. When I first heard him talk, I said to myself, "Well, if this isn't the limit! We have had the inspectors finding cavities in all kinds of ways and now they are coming along with an X-ray machine, and they have got us." But as I listened to his talk I learned two things. First, when they found the foundry couldn't make the thing sound, they went back to the designer and made him change the design—and if we can help educate the designer, it will help us all a lot.

The second point that I learned from Dr. Lester's talk was that there were some castings they couldn't make sound, at least, in the Watertown Arsenal. The designer couldn't change the design, and the foundrymen couldn't execute the casting so that it was perfectly sound. Then they scratched their heads and they said, "Well, we will locate those defects at the neutral axis, where they won't do any harm, and we will be able to use the casting." So there is a lot of hope. The X-ray, intelligently and reasonably applied in that way, ought to be of great assistance.

V. T. MALCOLM: I had the pleasure of working with Dr. Lester for some time in connection with high pressure valves and fittings investigations, and I want to say that the use of the X-ray is coming in those lines for examining the high pressure valve and fitting for the oil refinery and the power plant. The most valuable part in the control of foundry practice is to use the X-ray in the examination of a pile of castings. If you have a new casting that you are going to manufacture and are not sure of the shrinkage, or just what conditions you are going to find, you have that casting X-rayed and then study the situation out with the designer and the foundryman

for the proper location of the gates and header. We have found this to be of great value.

I may cite in one instance there was a certain casting that was examined, weighing approximately 1,000 pounds, that had passed a hydrostatic test. It was examined by the X-ray and a condition was found, the casting was opened and twenty pounds of sand was taken out of that casting. That is an actual fact.

Another thing that we learned was that 95 per cent of the defects found by the X-ray were due to molding practice, and 99 per cent of the 95 were due to carelessness. So I believe, with that in mind, that by the use of the X-ray we will eliminate a lot of carelessness in our foundry production.

Notes, Including Conversion Cost Data, on the Performance of Two Two-Ton Electric Steel Furnaces

By T. S. Quinn, Lebanon, Pa.

Introduction

Since the introduction of electric furnaces into this country, nearly twenty years ago, many articles of merit have appeared in the technical press, descriptive of electric furnace equipment and method of operation. Some data of a general character have been published on the cost of manufacture of steel through the medium of the electric furnace. However, nothing has come to the author's attention in the nature of complete statistical data on the actual operation of one or more electric furnaces over a given period of time.

In the following notes the author attempts to give to the steel foundry industry certain data covering a period of two years' operation of two two-ton Heroult acid lined furnaces, and the cost of conversion per ton of steel in the ladle, by months, over that period of time.

From the data thus compiled charts have been made to show graphically the effect of variation in furnace operation on certain factors such as combination of furnaces and cycles, and effect of these upon cost when operating under the usual two-part power contract with a demand and energy charge.

All data and cost figures submitted have been taken directly from the operating records without alteration or modification of any kind. Thus they reflect the results of two years' furnace operation in a typical steel foundry manufacturing small steel castings, as affected by those fluctuations in production that occur simultaneously with the high and low points of the company's order book.

Because of the complications that would arise in an endeavor to average the data pertaining both to carbon and alloy steels, it is particularly pointed out that such tonnage of alloy

steels (chrome, nickel, and high carbon steels) as were made by the company during this period, has been eliminated entirely in assembling the following notes. This was particularly important in view of the fact that this tonnage was not inconsiderable and would have affected materially the averages of figures for all steel made.

It is not the purpose in this paper to point out the advantages or disadvantages of any particular type of furnace or equipment, nor to recommend to others any particular method of operation or production; the sole purpose being to chronicle the operations of the company's two furnaces, without apologies therefor, and without making any comparisons with others. Anyone sufficiently interested can make such comparisons for himself and draw his own conclusions.

Type of Plant and General Character of Equipment and Product

The two furnaces, the operation of which is described herein, are located at the plant of the Lebanon Steel Foundry, Lebanon, Pennsylvania. This company manufactures, with the aid of electric furnaces, small steel castings, the average weight of which is about 18 pounds. This means that many castings are made up to, and occasionally over, 500 pounds in weight, and many weigh only a few ounces, each.

The bulk of the product comprises:

Motor car and truck castings
Railroad car and locomotive castings
General machinery castings
Valvebodies, fittings, and superheated steam castings
Miscellaneous small castings

This product is turned out in a main foundry building 115 feet wide by 700 feet long, with railroad service running its entire length.

The melting equipment consists of two two-ton Heroult electric furnaces, acid lined; No. 1 furnace having 1,000 kva. transformer capacity, and No. 2 having 800 kva. transformer capacity.

It seems opportune to mention that, in so far as the author is aware, the Lebanon Steel Foundry installed the first Heroult furnace in the United States for the manufacture of steel castings. This furnace was purchased in the fall of 1914 from the

United States Steel Corporation, which acquired the Heroult patent rights for the United States. This one-ton furnace subsequently was replaced by the two furnaces described in this paper.

No. 1 furnace with Thury control and No. 2 furnace with General Electric control both operate on a secondary voltage of 130 volts. The furnaces have water-cooled collars around the electrodes and water-cooled door frames, the water from which returns to a cooling pond and is again pumped to the furnaces after being cooled to a suitable temperature.

Twelve-inch amorphous carbon electrodes are used, as these have been found to give the most satisfactory results. Various other kinds and sizes have been tried, but resulted in higher costs per ton.

The roofs and side walls are of silica brick and the bottoms are of silica brick and sand. All parts of both furnaces, except the regulators, are interchangeable.

Each furnace is served by a traveling crane for the removal of roofs, electrodes, or metal, but charging is done by hand, no net economy being apparent in mechanical charging of furnaces of this capacity.

The molding department has the usual complement of molding machines of various types, and sand handling and mixing equipment. Most of the cores are made on machines and are dried in lift truck, rack type, oil-fired ovens, having pyrometer control. The cleaning department contains sandblast barrels and rooms, swing and stationary grinders, pneumatic hammers, electric welders, and cutting torches. Every casting is either annealed, normalized, or otherwise heat-treated by the utilization of car type, oil-fired ovens, equipped with recording pyrometers.

After fifteen years' experience in the manufacture of steel of different ranges of analyses, we have standardized on metal of the following chemical analysis for our regular commercial product:

Carbon	.22 per cent to .28 per cent
Manganese	.70 per cent to .80 per cent
Silicon	.35 per cent to .45 per cent
Phosphorus, maximum	.05 per cent
Sulphur, maximum	.06 per cent

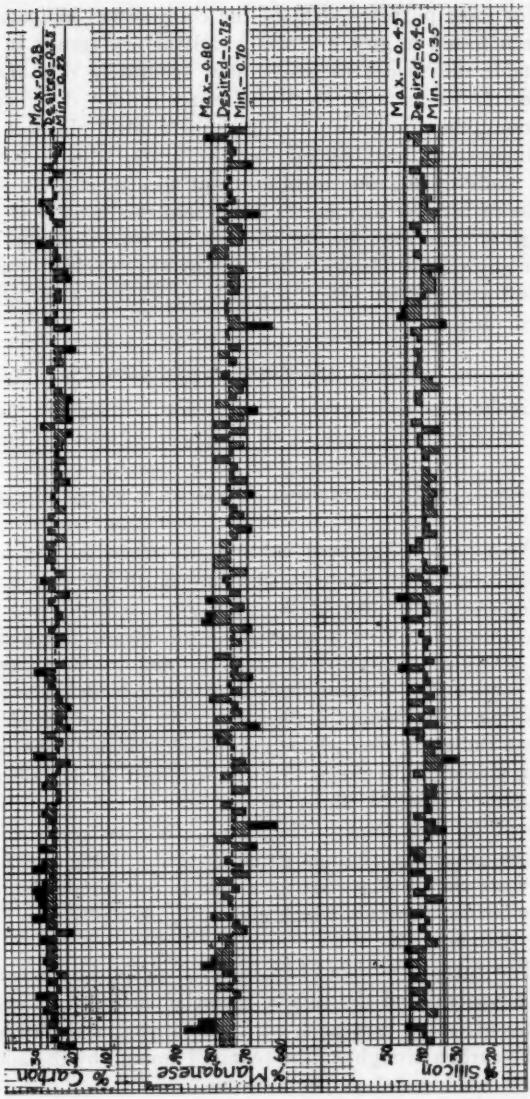

FIG. 1—CONTROL OF CARBON, SILICON AND MANGANESE FOR 131 HEATS

For most purposes steel of the composition indicated above has been found to give uniformly satisfactory results in service. To enable the reader to gauge how accurately this analysis is adhered to in an acid electric furnace under daily operating conditions, there is shown in Fig. 1 the control obtained on carbon, manganese, and silicon for 131 heats, which included all metal made during one month except special or alloy steel. It may be of interest to some to know that this control is obtained through a plan whereby the melters are penalized for heats in which any of the elements are out of the specified range, and are paid a bonus for heats in which the elements are within the desired range.

Method of Operation of Furnaces

In the two-year period of operation covered by this paper, there have been changes in our furnace practice from time to time, and it is not necessary to fully explain how our practice has varied, with the resulting effects on cost, quality, and production.

As a rule, it has been our practice when putting a furnace into operation after a general overhauling, to line the shell, sides, and bottom with silica brick. The roof is composed of silica brick shapes, and after it is mounted on the furnace with a sand seal between shell and roof, the bottom is shaped with silica sand to the contour desired to properly drain the furnace in pouring. The bottom is then set by the heat of the electric arc between the electrodes which are lowered through the roof, and broken pieces of electrodes that are arranged on the bottom. This operation is done by sintering the bottom into place in layers of about ¾ inch thick. The furnace is then ready for a run, with the exception of some patching to the lining which is done over week-ends. The roof as a rule is not removed until completely burned through, which generally takes places in the vicinity of the electrodes.

The furnace is then charged with scrap, the heaviest pieces on the bottom, and the lighter material on top. In about fifty minutes after the current is on, the charge is completely melted, and the carbon brought to the required amount by the addition of pig iron, wash metal, or hematite ore.

When the carbon content is adjusted, sand is added to the slag, and the temperature is raised quickly by increasing the power input. The reduction of nascent silicon then takes place from the slag so that at the end of fifteen or twenty minutes, some twenty points of silicon have been reduced.

At this stage a test that has been taken pours quietly, and not only lies dead in the test mold but really shows a slight cup. This indicates to the melter that the silicon content of the bath is actually about .20 per cent, and sufficient ferro-silicon in the form of 50 per cent lump is then added to insure the desired final proportion of silicon. It is interesting to note that contrary to the practice in the basic electric process, no carbonaceous matters needs to be added to the bath to bring about this reduction, the carbon in the bath itself being sufficient to effect the reaction.

A typical slag at the finish of a heat shows the following analysis:

Silica (SiO_2)	73.46 per cent
Iron Oxide (FeO)	5.60 per cent
Alumina (Al_2O_3)	6.49 per cent
Manganese Oxide (MnO)	11.25 per cent
Calcium Oxide (CaO)	2.12 per cent
Magnesium Oxide (Mg_2O_3)	1.08 per cent

While the slag is fairly viscous, it is never allowed to become so pasty or thick as not to run of its own accord from the furnace at pouring temperatures.

The whole operation is so timed that the bath will have reached the desired percentage of silicon when the heat is at the correct pouring temperature. The manganese is then added and the metal tapped, the total elapsed time from power on to power off being about one and a half hours, although, of course, subject to variation.

The operation described above is typical for our No. 1 furnace, the cycle on No. 2 being somewhat slower in every step.

The heat is tapped into a teapot-spout ladle which has been standard practice with us for a number of years.

This seems to be an opportune time to point out the exceedingly high temperatures at which it is necessary to pour

metal for light section steel castings, many of the sections being 3/16 inch and ¼ inch thick. Those who are not familiar with the pouring of castings of this section should have pointed out to them that, depending upon the section of metal and weight of casting that is to be poured, there can be easily a variation of 100 kilowatt-hours consumed per ton of steel.

Perhaps the most effective way of illustrating the results of hot metal on cost is to mention that the average, during six months' operations, of all spills, skulls, and metal pigged figured

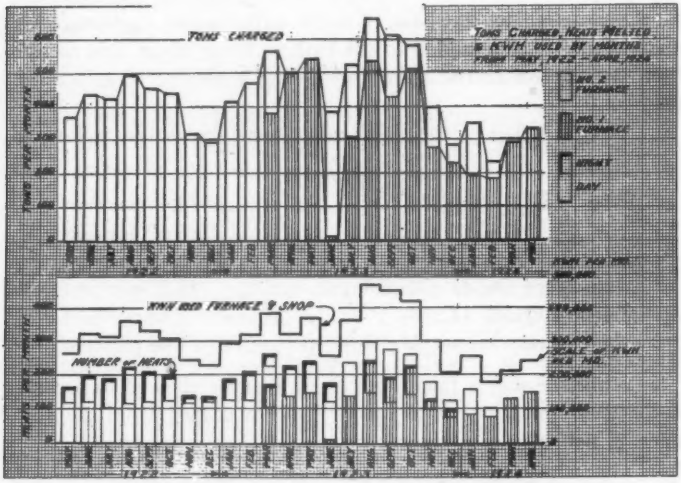

FIG. 2—MONTHLY DETAIL OF OPERATIONS

less than 2 per cent of total charge. The average melting loss over a period of six months by actual weight of charge and hot metal was shown to be approximately 6 per cent, when a good grade of scrap was used.

A monthly detail of some of the operations is shown in Fig. 2. The upper portion of this figure shows by months the tonnage charged and the division of this charge as between No. 1 and No. 2 furnaces.

The fluctuations in the chart indicate the extent to which we were affected by market and competitive conditions, except in the month of June, 1923, when our production was curtailed through a fire that cut off our operations for some days.

Between May, 1922, and March, 1923, all of our production came from No. 2 furnace. Following that time, however, most of the output was produced with No. 1 furnace, for in the month of February, 1923, we replaced the existing transformers for this furnace with a larger installation of 1,000 kva., which is now in service.

The lower portion of the chart presents the same information as the upper portion, except that the output is shown in heats per months subdivided between No. 1 and No. 2 furnaces, and furthermore between day-turn and night-turn. The heavy line between the two charts shows the total kilowatt-hours used by the furnaces and shop, and this curve follows very closely the production curve.

A summary of the monthly operations is shown in Table 1.

Charge and Production

The reader's attention is now called to the classification of items that make up the conversion cost of steel. The figures are tabulated in Tables 2-A and 2-B, month by month. All cost figures are on the basis of net ton of metal charged, without allowance for loss in melting. To compare costs of steel in the ladle, melting losses will have to be ascertained and deducted.

Necessarily the kinds of scrap available for making a good grade of electric steel vary in different localities. In the so-called Philadelphia district, we do not have the large tonnage of low phosphorus, low sulphur, light scrap that is available, for example, in Detroit and Chicago.

Because of the wide variations in cost of raw materials, partly due to the different classifications of scrap available in the larger scrap-producing centers, no cost items representing any part of a metallic charge are included in tables or graphs. In almost every district, there are sufficient varieties of scrap metals to tax the ingenuity of the management of a steel foundry in securing simultaneously a satisfactory mix and an economical combination for a furnace charge. As in most cases, we use

our own return shop scrap, consisting of heads and gates, defective castings, spills and skulls, and pigged metal.

Our practice, in charging the heaviest pieces on the bottom, and the lighter grades of scrap on top, enables the furnaces to start off more smoothly with less power fluctuation, than would be the case if heavy material constituted the top charge.

No cost figures are given per ton of production of steel castings. It is well known that the class of work made during

Table 1

Lebanon Steel Foundry—Summary of Operating Data

	Year 1922-23	Year 1923-24
Tons charged No. 1 furnace	880	3,814
Tons charged No. 2 furnace	4,305	1,349
Total tons charged	5,185	5,163
Number of heats, day turn, No. 1 furnace	248	1,355
Number of heats, night turn, No. 1 furnace	154	383
Total number heats, No. 1 furnace	402	1,738
Number of heats, day turn, No. 2 furnace	1,252	564
Number of heats, night turn, No. 2 furnace	699	51
Total number of heats, No. 2 furnace	1,951	615
Total number of heats, both furnaces	2,353	2,353
Pounds of electrode per ton charged	16.5	17.3
Kw. hrs. used for No. 1 furnace	474,785	2,187,850
Kw. hrs. used for No. 2 furnace	2,507,370	814,320
Kw. hrs. used for light and shop power	732,945	781,630
Total kw. hrs. used	3,715,100	3,783,800
Average melting time per heat, No. 1 furnace	1 hr. 49 min.	1 hr. 36 min.
Average melting time per heat, No. 2 furnace	1 hr. 49 min.	2 hrs. 6 min.
Average tons per heat, No. 1 furnace	2.19	2.19
Average tons per heat, No. 2 furnace	2.20	2.20
Kw. hrs. per ton, No. 1 furnace	540	574
Kw. hrs. per ton, No. 2 furnace	582	604
Kw. hrs. per ton charge used for light and power	141	151
Kw. hrs. per heat, No. 1 furnace	1,182	1,260
Kw. hrs. per heat, No. 2 furnace	1,284	1,323
Kw. hrs. per heat used for light and power	312	332

any one month has a very great influence on the cost of the finished product, and that without intimate knowledge of the class of work made, total cost figures are meaningless. It may be of interest to mention that our yield of good castings to metal charged ranges from 50 per cent to 65 per cent, depending on the class of work and the efficiency of the various departments.

The monthly variation in conversion costs per ton is shown in Fig. 3, in which we have compared the unit cost of conversion

Table 2-A

Monthly Cost Data Per Ton Furnace Charge—1922-1923

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
Conversion Materials:												
Refractories (repairs, including labor)	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50
Clay	.....	.....	.....	.....	.05	.....	.....	.....	.....	.....	.....	.....
Electrodes	2.53	1.52	1.06	.96	1.04	1.06	1.12	1.06	1.06	1.13	.90	.96
Ganister	.60	.56	.48	.43	.58	.62	.39	.46	.37	.48	.42	.36
Fuel (gas and oil)	.28	.28	.27	.26	.23	.23	.26	.36	.31	.38	.35	.33
Sand	.....	.....	.....	.....	.06	.07	.08	.07	.07	.04	.07	.06
Water and miscellaneous supplies	.34	.55	.52	.40	.23	.47	.38	.20	.38	.24	.40	.33
Total conversion materials	$ 4.25	$ 3.41	$ 2.73	$ 2.55	$ 2.69	$ 2.85	$ 2.73	$ 2.65	$ 2.69	$ 2.77	$ 2.64	$ 2.54
Labor:												
Furnace supervision	.70	.78	1.04	.97	.84	.74	1.32	1.19	1.19	1.15	.97	1.30
Furnace, general	1.29	1.30	.83	.81	.72	.87	.75	1.11	1.02	.97	.90	1.08
Ladles and pots	.57	.68	.61	.64	.44	.55	.48	.61	.63	.56	.55	.47
Total conversion labor	$ 2.56	$ 2.76	$ 2.48	$ 2.42	$ 2.00	$ 2.16	$ 2.55	$ 2.91	$ 2.84	$ 2.68	$ 2.42	$ 2.85
Power (furnace only)	8.14	7.62	7.71	7.23	7.18	7.45	8.85	9.03	7.71	7.19	6.57	6.84
Total conversion cost	$14.95	$13.79	$12.92	$12.20	$11.87	$12.46	$14.13	$14.59	$13.24	$12.64	$11.63	$12.23
Analysis of Power Cost:												
Demand charge (furnace and shop)	$ 2.82	$ 2.38	$ 2.44	$ 2.09	$ 2.22	$ 2.36	$ 3.29	$ 3.53	$ 2.49	$ 2.21	$ 1.83	$ 2.05
Energy charge—												
No. 1 furnace	....	....	....	.....	.....	.....	.....	.....	.....	.....	4.68	4.79
No. 2 furnace	5.32	5.24	5.27	5.14	4.96	5.09	5.56	5.50	5.22	4.98	2.43	.....
Total average cost furnace power	$ 8.14	$ 7.62	$ 7.71	$ 7.23	$ 7.18	$ 7.45	$ 8.85	$ 9.03	$ 7.71	$ 7.19	$ 6.57	$ 6.84
Energy charge, shop	1.21	1.34	1.36	1.30	1.35	1.17	1.55	1.68	1.18	1.12	1.79	.94

Table 2-B

Monthly Cost Data Per Ton Furnace Charge—1923-1924

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
Conversion Materials:												
Refractories (repairs, including labor)	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50	$ .50
Clay	.....	.06	.04	.05	.04	.05	.05	.05	.02	.04	.03	.03
Electrodes	.94	1.20	.93	.97	1.01	1.02	.88	1.11	1.27	1.20	1.13	1.07
Ganister	.42	.54	.53	.70	.73	.80	.96	.77	.71	.67	.66	.67
Fuel (gas and oil)	.29	.32	.39	.35	.28	.35	.50	.58	.61	.59	.37	.38
Sand	.05	.06	.05	.06	.06	.....	.07	.07	.07	.07	.07	.05
Water and miscellaneous supplies	.43	.34	.30	.26	.32	.42	.92	.49	.43	.86	.34	.58
Total conversion materials	$ 2.63	$ 3.02	$ 2.74	$ 2.89	$ 2.94	$ 3.14	$ 3.88	$ 3.57	$ 3.61	$ 3.93	$ 3.10	$ 3.28
Labor:												
Furnace supervision	1.14	1.48	1.18	1.03	1.02	1.03	1.34	1.65	1.23	1.44	1.50	1.37
Furnace, general	.99	1.24	1.18	1.18	1.32	1.24	.99	1.54	1.19	1.06	1.09	1.12
Ladles and pots	.45	.46	.56	.58	.35	.59	.59	.54	.54	.56	.55	.55
Total conversion labor	$ 2.58	$ 3.18	$ 2.92	$ 2.79	$ 2.69	$ 2.86	$ 2.92	$ 3.73	$ 2.96	$ 3.06	$ 3.14	$ 3.04
Power (furnace only)	7.29	8.51	9.31	8.15	8.53	8.61	8.50	10.23	8.84	11.43	10.10	9.52
Total conversion cost	$12.50	$14.71	$14.97	$13.83	$14.16	$14.61	$15.30	$17.53	$15.41	$18.42	$16.34	$15.84
Analysis of Power Cost:												
Demand charge (furnace and shop)	$ 2.42	$ 3.44	$ 4.01	$ 3.18	$ 3.43	$ 3.60	$ 3.37	$ 4.93	$ 3.83	$ 5.79	$ 4.60	$ 4.05
Energy charge—												
No. 1 furnace	4.87	8.57	5.24	4.76	4.87	4.85	5.20	5.40	4.89	5.73	5.50	5.47
No. 2 furnace	.....	5.00	5.39	5.92	5.62	6.05	4.96	5.77	5.17	5.37	.....	.....
Total average cost furnace power	$ 7.29	$ 8.51	$ 9.31	$ 8.15	$ 8.53	$ 8.61	$ 8.50	$10.23	$ 8.84	$11.43	$10.10	$ 9.52
Energy charge, shop	1.20	1.28	.87	1.21	1.32	1.31	1.79	1.46	1.73	1.90	1.38	1.34

materials, labor, furnace power, and shop power for each of the 24 months.

The power cost for furnace operation varies from a minimum of $7.18 per ton in September, 1922, to a maximum of $11.43 in February, 1924. Since the power consumed per heat is substantially the same at all times, this variation is due principally to the demand charge as between single furnace operation and two furnace operation. The power cost for shop lights and power showed a minimum of $0.87 per ton in July, 1923, and a maximum of $1.79 per ton in March, 1923. This item will bear no relation to tons melted, as the amount thereof is determined principally by the character of the finished castings that we produce.

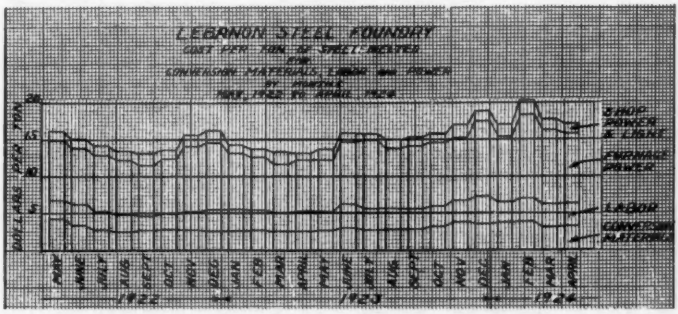

FIG. 3—MONTHLY VARIATION IN CONVERSION COSTS PER TON

Fig. 4 shows a comparison of conversion materials, labor, and power costs for the two years 1922-23 and 1923-24, indicating the general upward trend in all items of cost. In these two years the total tonnage produced was almost identical, but operating conditions were quite different, accounting in large measure for the variation.

Power Supply and Power Contract

The Lebanon Steel Foundry in common with most electric steel foundries purchases its current from the corporation serving the local district with electric power, which in this case is the Metropolitan Edison Company of Reading, Pennsylvania.

We believe that in very few instances would an investment in a power plant be warranted. The variations in load on a single isolated plant as compared to a large central station system would produce very difficult plant operating conditions. The load of an electric furnace is usually considered as a very desirable one from the standpoint of the power company, since the furnace arc produces a power factor of practically 100 per cent and a very high load factor. Consequently, the larger power companies usually provide rate schedules for electric furnace operation, which are quite favorable in comparison with their general power schedules.

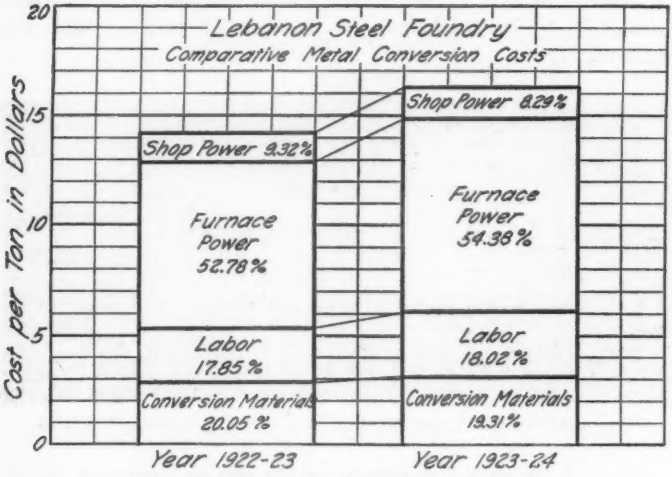

FIG. 4—COMPARISON OF CONVERSION COSTS

We experienced the usual difficulties of restricted supply and increased power costs during the wartime period. But shortly thereafter we were able to negotiate a new power contract under which service is delivered at 13,200 volts. From a standpoint of cost this power contract has three important sections, consisting of a demand charge, an energy charge, and a coal clause adjustment.

The demand charge fixed by the contract is at the rate of $1.10 per kilowatt of the maximum demand in the month. This demand is either to be measured by a suitable meter, or fixed with

reference to the total connected load. In our case both the power company and ourselves feel that the best results are secured by using the second method of determining the demand for billing purposes. Accordingly, our demand charge is made up of a furnace demand of $1.10 for each kilowatt of furnace transformer capacity in service, plus an added amount for the lighting load and the shop motor load. Our furnace transformers are rated 800 kva. and 1,000 kva., respectively. The manufacturers' name plate rating is based on a power factor of 90 per cent, so that our monthly demand charge for furnace load only is $792, $990, or $1,782 per month, depending upon whether we operate No. 2 furnace, No. 1 furnace, or both furnaces.

Under the operating conditions for the two-year period reviewed in this paper, our total demand charge has varied from $1,035 per month to $2,097 per month, this variation being due, as perviously noted, to the particular furnace or furnaces and motors in service for any one month.

The rates per kilowatt hour used vary from 1.25 cents, for the first 50,000 kilowatt hours per month, down to .80 cents, for the excess over 100,000 kilowatt hours per month.

Adjustment for coal cost is figured above and below a base price of $5.00 per ton, and is so provided as to reimburse the power company for any excess cost due to an increase of coal price above this amount, and to reduce our cost for energy in case coal prices decline.

The contract also includes a minimum monthly charge, but since this is less than the lowest demand charge which we could earn with our existing equipment, it would never work to a disadvantage except in case of a total shut-down for a period of a month or more.

Power Consumption and Power Cost

Table 3 contains an analysis of our power consumption and power bills for the period under review. It will be noted that there were three readjustments in demand charge due to different furnace combinations. The energy used per month varies, of course, in direct proportion to our total production, as may be clearly noted from Fig. 2. The coal clause adjustment came into

Table 3

Lebanon Steel Foundry—Power Bills by Months—May, 1922, to April, 1924

	Months	No. 1 Furnace	No. 2 Furnace	Shop	Total	Demand Charge	Energy Charge	Total
1922	May		215,890	49,010	264,900	$ 1,034.62	$ 2,394.20	$ 3,428.82
	June		257,320	65,880	323,200	1,034.62	2,860.60	3,895.22
	July		252,580	65,220	317,800	1,034.62	2,817.40	3,852.02
	August		290,905	73,695	364,600	1,034.62	3,191.80	4,226.42
	September		261,325	71,375	332,700	1,034.62	2,936.60	3,971.22
	October		250,460	57,340	307,800	1,034.62	2,737.40	3,772.02
	November		192,260	53,640	245,900	1,034.62	2,242.20	3,276.82
	December		175,280	53,420	228,700	1,034.62	2,104.60	3,139.22
1923	January		243,040	54,960	298,000	1,034.62	2,659.00	3,693.62
	February		263,255	59,245	322,500	1,034.62	2,855.00	3,889.62
	March	201,995	105,055	77,350	384,400	1,034.62	3,350.20	4,384.82
	April	272,790	.....	53,810	326,600	1,034.62	2,887.80	3,922.42
	Total year 1922-1923	474,785	2,507,370	2,232,930	3,717,100	$12,415.44	$33,036.80	$45,452.24
1923	May	300,400	.....	74,200	374,600	$ 1,305.22	$ 3,271.80	$ 4,577.02
	June	10,410	207,080	54,310	271,800	1,305.22	2,449.40	3,754.62
	July	182,800	133,615	51,985	368,400	2,097.22	3,222.20	5,319.42
	August	297,340	86,050	93,410	476,800	2,097.22	4,089.40	6,186.62
	September	239,860	121,715	93,425	455,000	2,097.22	3,915.00	6,012.22
	October	284,700	51,830	88,270	424,800	2,097.22	3,673.40	5,770.62
	November	161,460	65,615	79,125	306,200	1,327.32	2,724.60	4,051.92
	December	130,660	32,540	43,600	206,800	1,327.32	1,929.40	3,256.72
1924	January	104,300	87,585	66,315	258,200	1,327.32	2,340.60	3,667.92
	February	107,980	28,290	45,930	182,200	1,327.32	1,732.60	3,059.92
	March	171,400	.....	42,800	214,200	1,327.32	1,988.60	3,315.92
	April	196,540	.....	48,260	244,800	1,327.32	2,233.40	3,560.72
	Total year 1923-1924	2,187,850	814,320	781,630	3,783,800	$18,963.24	$33,570.40	$52,533.64

operation in the period between September, 1922, and August, 1923, and caused an increase in our total power bill.

The operation of our power contract is indicated graphically in Fig. 5, wherein has been shown the variation in monthly power bills when operating one or two furnaces, single or double turn.

The base scale shows the number of heats per month and covers a range up to 500, and the vertical scale shows the total bill for furnace and shop power, eliminating coal clause adjustment. No. 2 furnace, which has the smaller transformer capacity, can produce 125 heats single turn, or about 225 heats double turn, and the power bills, exclusive of coal clause adjustment

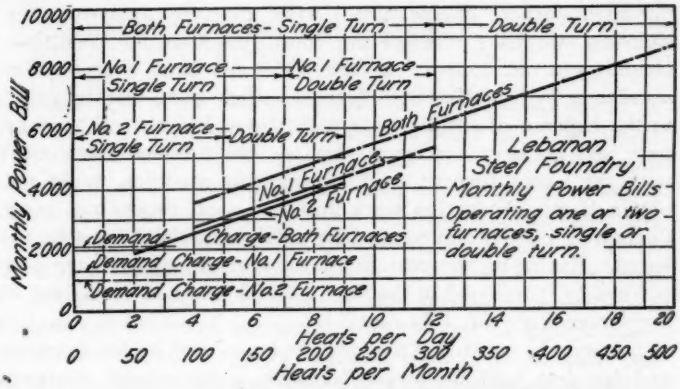
Monthly Power Bill
10000
8000
6000
4000
2000
0
Both Furnaces - Single Turn
Double Turn
No. 1 Furnace Single Turn
No. 1 Furnace Double Turn
No. 2 Furnace Single Turn
Double Turn
Both Furnaces
No. 1 Furnace
No. 2 Furnace
Demand Charge - Both Furnaces
Demand Charge - No. 1 Furnace
Demand Charge - No. 2 Furnace
Lebanon Steel Foundry Monthly Power Bills Operating one or two furnaces, single or double turn.
0 2 4 6 8 10 12 14 16 18 20
Heats per Day
0 50 100 150 200 250 300 350 400 450 500
Heats per Month

FIG. 5—VARIATION IN MONTHLY POWER BILLS

when operating it, are shown by the lowest line on the chart. It will be noted that the demand charge with this furnace in operation is about $1,000 per month, and that for the maximum production double turn, the power would cost $4,300 per month.

Similarly with No. 1 furnace in operation we can produce about 175 heats single turn and 300 heats double turn, under which conditions our power bill would vary from a demand charge of $1,300 to a maximum of about $5,350 per month, as shown by the middle line.

For productions in excess of 300 heats per month, we would have to operate both furnaces. On single turn we can produce

300 heats, which is the same output as that of No. 1 furnace on double turn; and with both furnaces double turn, we can produce a maximum of 500 heats per month. Under these conditions the power bill would vary from a demand charge of $2,100 to a maximum of $8,700, as shown by the upper line.

Referring again to Table 3 showing our power cost, it will be noted that the energy charge for the two years is substantially the same; i. e., something over $33,000 for between 3,700,000 and 3,800,000 kilowatt hours. However, the demand charge was nearly 50 per cent greater in the second year than in the first, due entirely to the fact that in certain months we operated two furnaces single turn in preference to operating one or the other furnace double turn. After carefully analyzing this situation, we have reached the conclusion that for conditions obtaining in our foundry we are better off from a production standpoint by operating both furnaces single turn, than by going to the expense of setting up a night force for a small tonnage over and above a maximum that we can produce single turn with the larger furnace. Of course, this condition might not obtain if our production were uniform at all times, but under fluctuating market and competitive conditions, this cannot be assured. Excluding the coal clause adjustment, the average cost per kw.-hr. purchased in the year 1922-23 was 1.22 cents, and in the succeeding year, 1.39 cents.

It may be noted that the kilowatt hours used by the furnaces and for shop light and power increased in the second year over that in the first. This increase amounted to about 3 per cent. There is no special reason for this increase that can be accounted for in furnace operation, and it was caused principally through variation in the character of finished product from time to time.

No. 2 furnace apparently used from 6 per cent to 8 per cent more power per heat than No. 1 furnace, largely due to the fact that the melting time is less for the larger installation. Consequently, the electric energy is more effectively applied to the bath, and there is less radiation from the furnace shell and doors. The average melting time with No. 1 furnace is one hour and thirty-six minutes, whereas the melting time with No. 2 furnace is one hour and fifty-seven minutes, or approximately 20 per cent greater for the same weight of charge.

This extra melting time of something over twenty minutes per heat would account for almost all the increased power consumption of No. 2 furnace.

Labor

Very little need be said in explanation of the cost figures submitted under this heading, except that furnace supervision represents the melter in charge of the furnace. Furnace general labor includes helpers, weighing of charges and additions, and the transportation of charges to the furnaces.

Labor on ladles and pots includes the preparation of this equipment to receive the metal, but does not include pouring the metal.

Refractories—Roof and Lining Renewals—Repairs and Maintenance

It will be noted that a uniform cost for refractories of 50 cents per ton of charge is shown for the entire two-year period. This is accounted for by reason of the fact that this amount was set up as a reserve for that period of time. Our previous experience had taught us that this figure was about right, and that a more uniform monthly cost could be obtained by which to make a comparison than when no refractory cost appeared for a month or two, and it then became necessary to overhaul a furnace and to charge one month with the cost of these repairs.

In the matter of repairs and maintenance, the company has pursued a policy of keeping the furnaces in first-class mechanical and electrical condition in every respect. This has minimized shut-downs due to neglect, and has made for a more continuous operation and the elimination of expensive periodical replacements.

Some data on the life of the refractories may be of interest. A good acid bottom, properly put in place, should never have to be renewed. The side walls from the slag line up to the roof should have a life, with patching, equal to the life of the roof. The life of the roof will vary from 200 to 1,000 heats, depending largely upon the secondary voltage used, the temperature of the metal poured, and the cycle of operations. Our records show a maximum run of 1,015 heats on one roof without renewal, but

this was under exceptionally favorable conditions. We have adopted for our operation a secondary voltage of 130 volts, because we can put the maximum of our transformer capacity into the furnace at this voltage and get the best refractory results, and at the same time, maintain a slag of the proper consistency. As stated elsewhere, the side walls and roof are of silica brick. Sharp silica sand is used for patching bottom, and ganister for patching side walls.

Electrodes

Both graphite and amorphous carbon electrodes have been tried, the latter of two diameters. Both have proven satisfactory from the standpoint of operations, with the advantage of ease in handling with graphite, but of a lower cost with amorphous carbon.

Great forward strides have been made in the manufacture of electrodes since we operated our furnace ten years ago, with the result that electrodes are now made of better materials, are truer to size, and are physically stronger than previously. This has been a big factor in making for more continuous furnace operation, to say nothing of the extent to which it has lightened the labors of the furnacemen, who in former times spent a large part of the day on top of a hot furnace, wrestling with troubles due to broken or imperfect electrodes. It is only fair to the electrode manufacturers to point out that furnace practice as well has improved, so that their electrodes do not get the abuse now to which they previously were subjected. The design of electrode holders has on most furnaces been changed to eliminate the difficulties that originated from this source.

In making comparisons of cost of electrodes consumed monthly, it should be borne in mind that the electrode consumption is affected considerably by the cycle of furnace operation. By way of illustration, it is not possible to achieve the same results on the furnace running day turn only, as on a furnace running day and night, as the loss by oxidation is very great during the overnight cooling period. Also, the contraction and expansion that take place with the starting and stopping of the furnace increase the liability of breakage.

Water and Miscellaneous Supplies

This item of cost includes water, furnace tools, test molds, shovels, etc. Where water is not plentiful nor very inexpensive, a cooling pond is desirable for the furnace water and for cooling the transformers. At Lebanon, we have a cooling pond and spray nozzles which reduce the temperature of the water and insure satisfactory conditions in the hottest weather.

It would seems pertinent to make mention here of the water-cooled door frames which have resulted in more satisfactory furnace operation, and have lowered our refractory cost. Before the general use of water-cooled door frames on electric furnaces, the brick burned out very rapidly at the door jams and arches. But the water-cooled door frame has completely obviated this difficulty, and has, to our knowledge, reduced the power consumption per ton of charge.

Conclusion

As stated earlier in this paper, it was not the intention of the author to prove or disprove any particular theory or practice, but it would seem incomplete and unsatisfactory to refrain from mentioning certain conclusions reached at Lebanon, in the light of the data given in this paper.

Notwithstanding the fact that it is less economical from the standpoint of conversion costs to operate two furnaces day turn, instead of one furnace day and night, we note that our overall cost of production of steel castings has been less, running two furnaces day turn, than when operating one furnace day and night.

There are many items of cost in the production of steel castings other than the cost of metal, which increase when a day turn is supplemented by a night turn; and there are, in night operations, many intangible items of cost that creep in, or increase, especially if it is not possible to run the night turn to the same capacity as the day turn.

In most foundries the limiting factor of output is the capacity for producing metal. This has been the case at Lebanon until recently, when we increased our molding facilities to a point that enables us to fix our capacity by this department's ability to produce, rather than by furnace output.

The practical effect of this has been that we do not put on a second furnace day turn unless we are going to use it sufficiently to insure that it will earn its demand charge; whereas, previously we occasionally put on a partial night turn that produced a limited and varied number of heats, resulting in a higher total cost per ton of steel castings produced.

It is conceivable that the demand charge in some localities might be so heavy as to force on the manufacturer the less desirable alternative of running a furnace day and night before considering the operation of two furnaces day turn. From the figures assembled above, we have been able to ascertain approximately the number of heats that either of our furnaces must make before putting it into operation with assurance that it will justify the demand charge.

Discussion—Notes on the Overall Performance of Acid Electric Furnaces

CHAIRMAN J. H. HALL: This paper, gentlemen, seems to me really to be a classic. It marks a milestone in the discussion of electric furnace efficiency. To my knowledge, for many years we have seen figures presented on the cost of operation of electric furnaces largely based on opinion. This paper is a report on cold facts of the very greatest value to all of us.

W. J. PRIESTLY: I think Mr. Quinn deserves a whole lot of credit in writing a paper of this kind. He has opened up and given foundrymen a whole lot of cost facts that they have never been able to get before.

There are two things that I think might bring forth a little discussion from the men here. The chairman has invited us to tell our own experiences, exchange ideas, bring out different facts, and with that in mind, I would like to give our experience in operating the furnace in the manner by which Mr. Quinn states that he picks up nascent silicon to .20. It has been my experience, and many of you may also have noted, that by running a furnace very hot and picking up silicon you may get a perfectly quiet, dead metal in your test mold, but this same metal will rise and blow in the molds. We have given considerable study to this condition from two points of view.

You have no means of determining your silicon content after run-

ning your furnace hot towards the end and picking up high silicon. You estimate it as .18 to .20 silicon, when the metal quiets down and begins to recess in the mold. But if your furnace is running unusually hot, you may run up as high as .30 silicon, and by adding a fixed amount, you get a wide range of silicon in your casting. I notice here that Mr. Quinn gives his silicon range from .35 to .45. Now, we have found that when you melt steel it contains oxides and other gases, hydrogen and nitrogen, and this gas may be carried over into your mold, into your castings. It is well to get a good action on your bath before you tap. That action is an indication that you are freeing the metal from other occluded gases.

I would like to have other members give their experience and what their results have been in regard to melting down low and burning out silicon to the lowest point possible (.05 to .07, for example) and then adding .30 to .35 silicon and comparing that with metal where they have about .20 residual silicon and adding .25 more. My experience has been that by melting down and burning out all the silicon possible, getting a good action on your metal and freeing it from other occluded gases and adding .30 to .35 points of silicon, steel is obtained that lays deader and will not rise in the molds as often as when a higher residual silicon is first obtained.

Mr. Johnson brought up a question after Major Bull made his report, asking for the limits on sulphur. I think that what the foundryman is most interested in is the effect the sulphur has on the physical properties of the casting, and not the machining properties.

I notice that Mr. Quinn has run his manganese up to .70 to .80. This is good, as it helps deoxidize the metal, helps clean it, and with sulphur running around .06, there is no doubt but that high manganese has a beneficial effect. Sulphur in the steel is detrimental, first of all, when it exists in the steel as iron sulphide. If you add manganese, it leaves it in a less harmful form as manganese sulphide.

Then, another thing, when Mr. Quinn gives the slag analysis I notice that he gives the lime content as 2.00 per cent. We have been working recently with a higher lime content in the silicon slag. The first thought is that as soon as the acid condition is neutralized there is danger of it becoming basic and cutting the lining. We have run slag as high as 15 to 20 per cent CaO without cutting the lining to any extent whatever. We have found that, besides aiding in deoxidation, a high lime content tends to reduce the sulphur in the steel.

I should like very much to get expressions from some of the other foundrymen here with regard to silicon content, and the relative effect resulting from the addition of ferro-silicon to the steel, compared with nascent silicon taken from the slag. I have noticed the same thing in open hearth work and in basic electric practice. If the silicon

is added too early, it takes into solution excess gases that are thrown off as soon as the metal freezes.

A. W. LORENZ: I would like to ask Mr. Quinn whether that saving of six to eight per cent in current consumption due to the installation of the larger transformer would be offset by the higher demand that you have to pay with the larger transformer capacity, or whether you have a real saving there. I would like to find out whether by installing a larger transformer one might effect a saving.

S. C. JOHNSTON: So far as the running of the silicon down and his melt down before the addition of the final increment, so far as my personal experience is concerned, we find that same result as he did, that when we cut our silicon low and add the silicon at the final finishing of the metal, we get a better result. When, however, we cut our silicon below .10 it increases our power consumption, because the metal becomes more basic and doesn't finish as quickly and lags back, while if we bring our silicon from .10 to .20, we will save on our power consumption and come in very rapidly, all other things being equal, such as carbon and manganese, etc. That was one of the reasons why in my personal experience we failed in the old single phase furnaces of making what is known as dynamo steel, that you could not handle steel very well under the condition of the lower silicon and manganese contents without a three-phase furnace.

T. S. QUINN: I agree with Mr. Priestly that it is desirable to get a good boil on a bath, and that you finish the heat, so far as the silicon addition is concerned, either by the reduction of the silicon or by the addition of ferro-silicon as nearly towards the end of the heat as possible. But we must have silicon control, and we have found that as we prefer to get a little action on the bath by the addition of some MnO, that if we get a boil on a bath and let that boil out we have varying contents of silicon after the violent action of the bath has subsided. If, however, we permit the heat to come back to a quiescent state, which is indicated by that point which the bath has come to after it has reduced to .20 silicon, we have a point that we can gauge that supply when the test mold cups satisfactorily. It is true that a heat will cup only with a higher content of silicon when the bath is hot than when it is not so hot, but as in the pouring of the tests, the temperature can be observed by the melter, he can gauge pretty accurately, from experience, as to whether or not it is a normal heat or whether it is a heat that is too hot at the time he is looking for his cups.

Regarding the matter of sulphur, we don't like a sulphur content any higher than we can avoid, within reasonable limits. If we were able to get our sulphur down under .03, I believe we would, and I know that we have in the past run into complaints from some of our customers, particularly if the machining operation involves any

threading. Therefore, from the practical standpoint, and disregarding for a moment the metallurgical standpoint of viewing sulphur, we want a sulphur content of about .04 minimum. In the maximum that I gave of .06, for commercial reasons we wouldn't want our product to run over that, but up to .05, which is, as I have stated before, about our average run of steel, we have found that very satisfactory.

As to the addition of lime, in pouring excessively hot melts, such as we have poured for small castings, the slag has a tendency to adjust itself as to silicon content almost regardless of what we do. Nevertheless, we are able to increase our lime content in our slags up to say 15 per cent, if we wish to do so. But the practical effect of the addition of lime is that we produce a more or less watery slag, and that, while it is probably true that lime, theoretically, will displace iron oxide, practically a watery slag in castings is much more objectionable than any benefit we might get from the lime to offset that. A watery slag, in pouring of small steel castings, is about the meanest thing you can have, from the standpoint of subsequent cleaning, that you have to give them. There is apt to be more welding due to slag spots and the like.

Answering Mr. Lorenz, I would say that question can be perhaps best answered with a paper and a lead pencil. The increase in demand due to increase in the size of transformer and the demand charge is small. The benefits to be gained by that increase are considerable, in that in the early stages of the heat you can make your time with all the power you have available, and then if you want to finish slower and you think it is good practice to do so, you can cut your current back in finishing the heat.

W. J. PRIESTLY: Could I ask in this paper whether, after getting .45 silicon by the addition of ferro-silicon, there are any other deoxidizing agents added?

T. S. QUINN: Yes, a small percentage of aluminum, in the pouring.

W. J. PRIESTLY: To bring out another point, we have added .30 per cent silicon in the form of ferro to a bath with .05 silicon and obtained sound metal.

T. S. QUINN: I would like to ask Mr. Priestly if that is running basic or acid and what the average weight of castings were that were poured from heats as low in silicon as .05.

W. J. PRIESTLY: I didn't want to give the impression that they were poured at .05 silicon. They were poured at .30 to .35, and .30 points added. The castings weighed anywhere from 20 pounds to 100 pounds. Acid operation.

T. S. QUINN: How long were you successful in maintaining that practice?

W. J. PRIESTLY: Well, it didn't cover a definite period of a year, like you cover in this paper, but it is under varying conditions, some more unfavorable than you would have in an electric furnace. I have done it in an acid open hearth furnace, and you get the same thing in a basic electric furnace. You will get a metal that won't lie quiet if you add your silicon too early.

MR. ROCK: I don't think that the presence of silicon necessarily indicates the absence of oxides. It is usually considered that it does, but I have seen a very high silicon content with very high oxides, especially in dynamo steel. We had a case one time in treating a heat of dynamo steel, low carbon and manganese, where we ran the silicon up to 1.75, with an abundance of aluminum, and it still came back in the mold. If, however, the bath is well boiled down and the oxygen is gotten rid of by carbon, we produce the boiling and get rid of the impurities in that way; a small amount of silicon or a small amount of other deoxidizer will have a beneficial action and completely deoxidize the steel, but I think it is a mistake to judge the completeness of the deoxidation by the amount of oxides left in the steel. You are all familiar with Brinell's rule. It is held by a good many of the metallurgists and writers on electric furnaces that silicon reduced from the slag or from the lining is more beneficial than silicon added. I don't see any reason for that unless it is due to the fact that when there is reducing action on the silicon the silicious sonims in the bath, the particles of slag and particles of silicon that are suspended in the bath, are being reduced and gotten rid of in that way. Otherwise, I don't think there is any reason why the silicon reduced that way is any more beneficial than silicon added. It has not been our experience that that was the case.

H. A. NEAL: I think there is only one reason why silicon reduced from the bath is more beneficial than silicon added. That is the fact that in reducing silicon from the bath you introduce a time element in the treatment of your steel. Now, it is perfectly possible and feasible in some very fast working furnaces to tap a three-ton heat of steel in less than an hour's time. In that case you scarcely allow time for any silicon reduction. Speaking in the vernacular, you don't give your bath time to clean up, and that is the only reason why reduced silicon is more effective than added silicon.

MR. WEISER: May I ask just one question of Mr. Quinn? He makes the statement that they have standardized on a secondary voltage of 130 volts for three reasons. I would like to ask what the effect of raising or lowering the voltage would be, both on the slag and on your brick.

T. S. QUINN: A voltage reduced in an acid furnace, say below 110 volts, has this effect on the slag, that the heat cannot penetrate the slag and the electrodes bury themselves into it and become short-

circuited with the metal. That is, after the bath has been melted. In trying to establish contact before the bath is melted on a voltage that, say, is around 100, it is very difficult to get the current flowing. It is true that in Europe I have seen furnaces starting on cold scrap with 80 volts, and I cannot account for the reason, but they seem to get away with it, whereas I can recall the time when we first started to operate electric furnaces that we couldn't get by with 80 volts; we couldn't get the heat started. I can only account for it by the fact that all the furnaces I saw had a different frequency. Whereas ours is 60 cycles, I think those furnaces over there were operating on 25. That might make a difference in the flow of current. On a higher voltage after you get beyond that point where you can maintain an arc and have smooth operation, I see no advantage in increasing the voltage beyond that point, in so far as the operation of the furnace is concerned, but there are many reasons why it is detrimental. The longer arc will, of course, attack your roof and your lining and will give you a slag for a given analysis that will probably be too fluid. Of course, the increase in voltage permits of a greater number of kilowatts being put through your copper, but if you make your copper heavy enough, it seems to me there is no advantage in raising the voltage beyond that point which I have just stated, and which we have found to be about 130 volts.

Broadening the Field for Steel Castings Through the Use of Alloys and Heat Treatment

By F. Grotts, Peoria, Illinois

There is no question but that the field for steel castings can be increased by the use of different alloys and suitable heat treatments. The proof of this lies in the fact that greater strength, toughness, resistance to shock, and wearing properties can be obtained with small costs and practically no change in machinability.

The common alloys used are chrome and nickel, in some cases vanadium and molybdenum. The alloys are added either single or collectively; that is, chrome, chrome nickel, chrome vanadium, chrome nickel molybdenum, etc. The best treating consists in single and double annealing, quenching and drawing. The treatments in general are similar to those used in treating bar stock and forgings. The original anneal requires a considerable length of time to break down the casting structure. Temperatures varying from 1600 to 1700 degrees Fahr. are customary and the length of time will vary according to the tonnage treated and the type of furnace.

It is very essential that all castings be annealed before being subjected to service or machining operations, especially if the carbon content is high or alloys are used. Improperly annealed castings, excepting where the carbon approximates .20 per cent, means tool trouble, slow machining times and probably service failures.

If the casting structure persists after the annealing operation, an even distribution is impossible by the quenching and

drawing operations. It is especially desirable to have well annealed castings, where they are to be quenched, otherwise hardening cracks may result.

Analysis should always be within set limits, as the physical properties and treatments are more easily controlled. The question of meeting specified chemical analysis is one often discussed. This point, however, is easily met, as the following data will prove. It might be mentioned that these foundries are representative and located respectively in Wisconsin, Illinois and Indiana. The specified material was .30-.40 carbon, .05 maximum sulphur and .05 maximum phosphorus; to be used for hard

FIG. 1—THIN SECTION STEEL CASTING, EASILY MACHINABLE, REDUCES PARTS, RIGID AND STRONG.

service after being quenched and drawn to a scleroscope hardness of 35 to 45.

	C.	S.	P.	Mn.
Wisconsin	.34	.045	.035	.55
Illinois	.39	.04	.03	.50
Indiana	.35	.05	.06	.60

Not only may castings be purchased to practically any specification, but the average defects, such as shrinkage, can be controlled by suitable patterns and foundry practice. Difficult thin sections never before attempted can be readily cast with small effort, an illustration of this type of casting being shown in Fig. 1. The importance of such a design is found in machinability, unit assembly, strength and service.

Low Carbon Steel Castings

By low carbon steel casting is meant those that have an average chemical analysis of .16 to .25 carbon. They are used in the annealed condition except in some cases where a hard

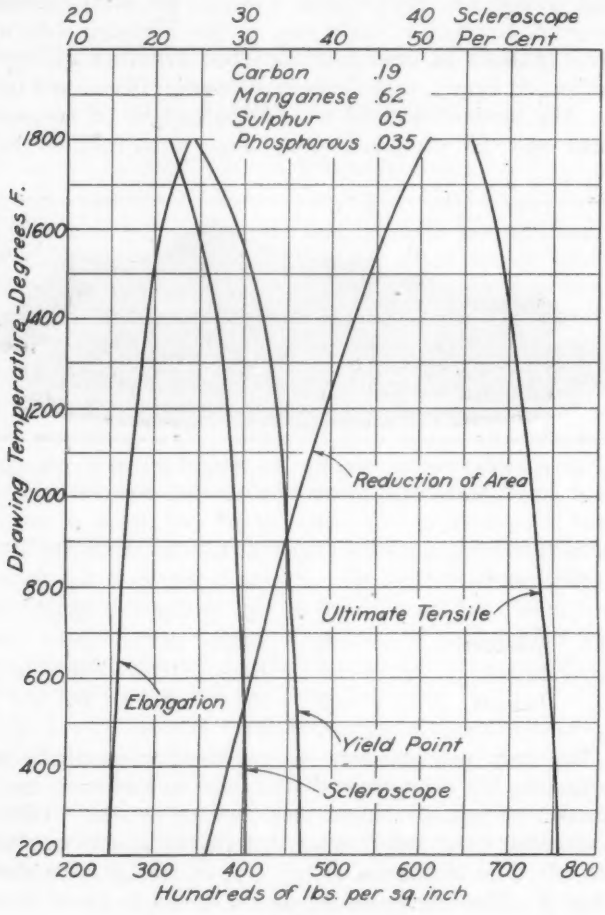

FIG. 2

surface is required. This property is obtained by carburizing and hardening. The parts to be carburized are packed and heated at 1650 to 1700 degrees Fahr. for the length of time necessary to give the desired depth of case; then cooled in the box and reheated or else quenched directly from the box. This last method, although not generally recommended, gives results quite satisfactory in some applications. Oxidation and distortion are reduced to a minimum, but maximum refinement of the core and case are not attained.

Gears and sprockets are successfully made from low carbon steel and case hardened to give good wearing properties. Such parts find extensive application in farm implements, foundry and factory equipment.

It is possible to improve materially the tensile strength of this low carbon material by quenching in water from a temperature of 1600 to 1625 degrees Fahr. This treatment is sometimes resorted to in order to increase the stiffness or to prevent easy bending. There is no danger from cracking, and the results are sometimes worth while. A study of the curves in Fig. 2 shows attractive possibilities.

Brackets, axle housings, supports, columns for automotive and railroad work can be designed successfully as material reductions in weight are possible without sacrificing quality or service performance.

A casting of this analysis further makes an exceptionally good carburizing box, as the cost is low and the heat hours will average from 500 to 600. These data compare favorably with special alloy boxes and without the enormous investment.

Correct reinforcing is necessary, especially in large boxes, as the casting at high temperature will distort when loaded heavily and finally fail.

Medium Carbon and High Carbon

Medium carbon castings average from .30 to .40 carbon, while the high carbons take into consideration those from .60 to 1.00 per cent.

The medium series give very good results in general when either annealed or quenched and drawn. The section has much

to do with the treatment and in intricate designs, troubles from quenching cracks are sometimes experienced. This danger is obviated by cooling in oil or hot water. These methods may be modified by quenching in water a definite length of time; for illustration, cool castings in water for five seconds, ten seconds,

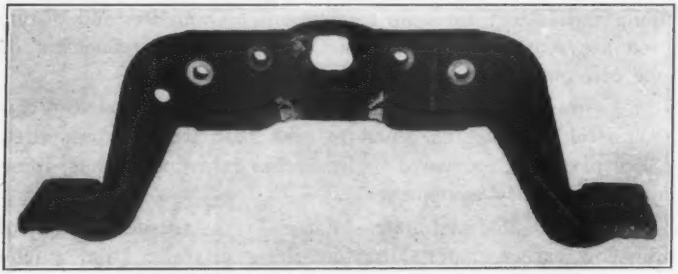

FIG. 3—TRUNNION MADE OF CAST STEEL, GREAT STRENGTH AND TOUGHNESS AFTER TESTING.

fifteen, etc.; then examine for hair line cracks and take scleroscope hardness. After this test it may be found that approximately ten seconds may give the desired properties.

In general, medium carbon castings have a very wide use. The trunnion (Fig. 3) is treated to give toughness and shock-resisting properties. Axles and tractor parts of this material will stand up especially well.

This material is especially applicable where castings of considerable strength and toughness are desired. Fig. 4 shows a medium carbon sprocket treated for wearing properties and still machinable. This last property is necessary because the sprocket must function in fairly close limits. The treatment given the castings of Fig. 4 is tabulated below:

Anneal—1,600-1,650 degrees Fahr.
Quench in water—1,525-1,550 degrees Fahr.
Drawn to scleroscope hardness of 40-45.
Ultimate tensile—115,000 pounds per square inch.
Elongation—8-10 per cent.

The higher carbons (.60 to 1.00) find application chiefly in rolls. They are, however, applicable to parts requiring hard

ness and high physical properties; for illustration, some dies, tools and fixtures.

Steels

Chromium in varying amounts greatly increases the hardening ability of castings. File hardness or high scleroscope is obtained by quenching and drawing after annealing. Extremely high physical properties in general can be obtained where the sections are suitable for quenching and drawing. A very diffi-

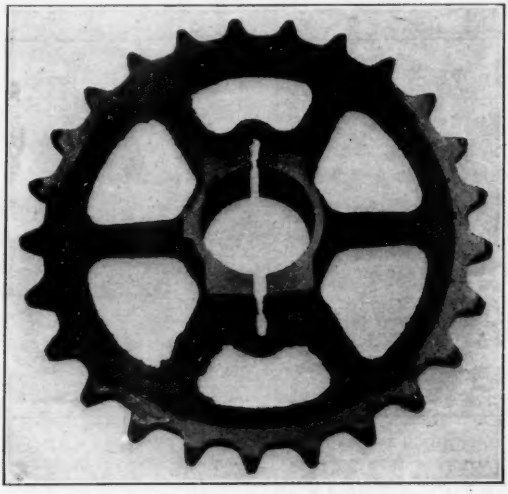

FIG. 4—SPROCKET MADE OF .30-.40 CARBON STEEL, QUENCHED AND DRAWN TO SCLEROSCOPE 40-45.

cult job is shown in Fig. 5. This casting requires hardness and toughness in order to withstand abrasive action. The cutting edge or grouser is hardened to scleroscope 65, while the supporting sections are toughened to scleroscope 40. The analysis follows:

.75-1.00	Chromium
.45- .55	Manganese
.05 Max.	Sulphur
.04 Max.	Phosphorus
.35- .45	Carbon

It is especially of importance to note that this steel is readily machinable and gives remarkably high properties after treating, which recommends it in parts where maximum hardness and wear are necessary. Dredging machinery, ditching machinery and tractor castings can utilize this analysis to advantage.

In Fig. 6 should be noted that quenching in hot water from a temperature of 1,550 degrees Fahr. and drawing at 700 degrees Fahr. gives a tensile strength of approximately 200,000 pounds

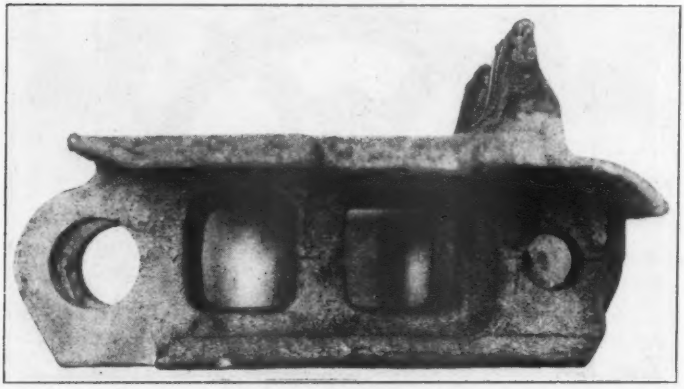

FIG. 5—TRACTOR LINK MADE OF CHROME CARBON STEEL, QUENCHED AND DRAWN. CUTTING EDGE 60-65 SCLEROSCOPE—OTHER PARTS 35-45 SCLEROSCOPE.

per square inch and an elongation of four per cent; also that drawing at 1,100 degrees from the quenched condition gives a tensile strength of approximately 140,000 pounds per average square inch and an elongation of about 14 per cent.

Chrome Nickel

Many different combinations of chrome and nickel can be used. It depends entirely on the desired physical properties. The design must always be kept in mind as some sections or parts will not permit drastic treatment owing to distortion. Railroad parts (frogs and switches) made of high nickel

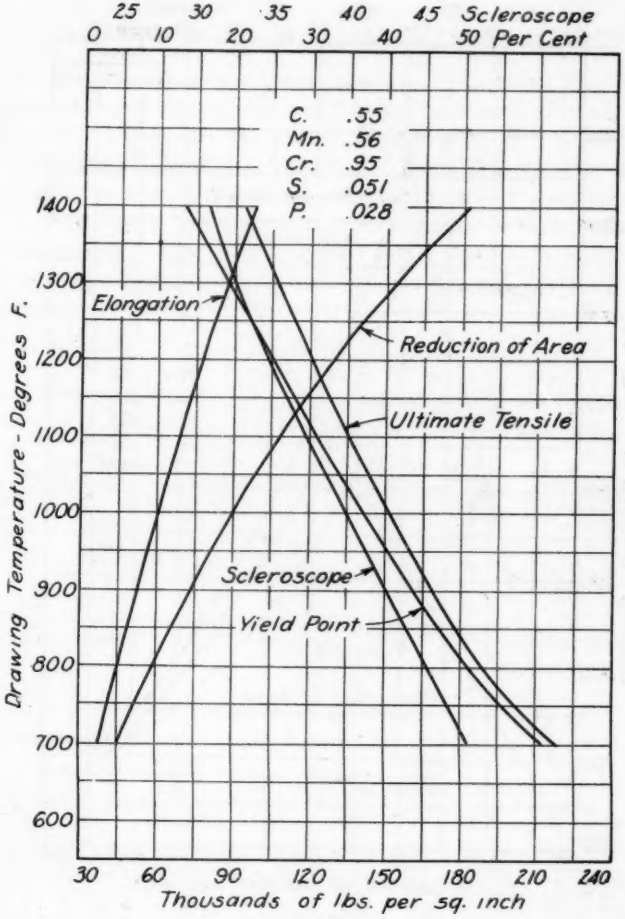
25 30 35 40 45 Scleroscope
0 10 20 30 40 50 Per Cent
C. .55
Mn. .56
Cr. .95
S. .051
P. .028
Elongation
Reduction of Area
Ultimate Tensile
Scleroscope
Yield Point
Drawing Temperature - Degrees F.
1400
1300
1200
1100
1000
900
800
700
600
30 60 90 120 150 180 210 240
Thousands of lbs. per sq. inch

FIG. 6

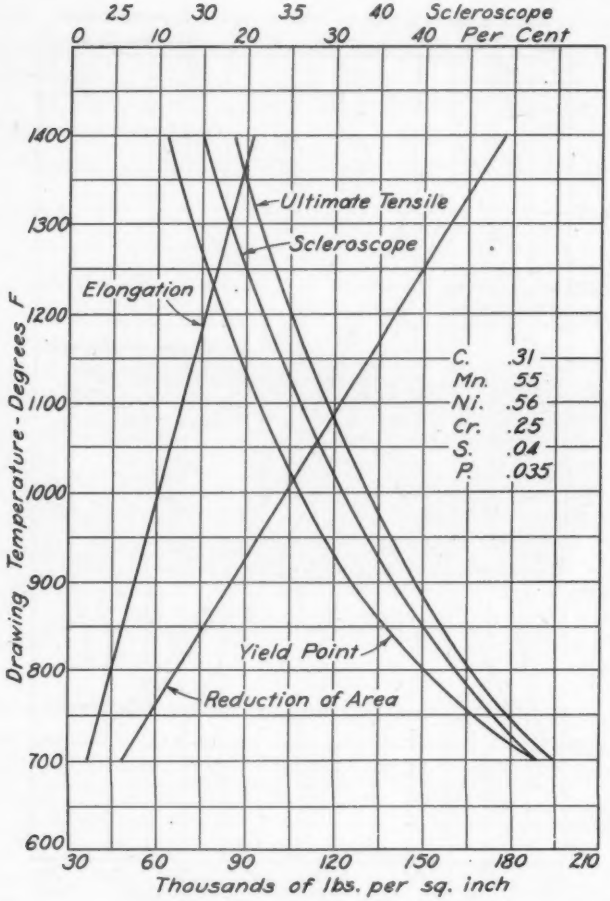
25 30 35 40 Scleroscope
0 10 20 30 40 Per Cent
1400
1300
1200
1100
1000
900
800
700
600
Drawing Temperature - Degrees F
Ultimate Tensile
Scleroscope
Elongation
C. .31
Mn. .55
Ni. .56
Cr. .25
S. .04
P. .035
Yield Point
Reduction of Area
30 60 90 120 150 180 210
Thousands of lbs. per sq. inch

FIG. 7

chrome should give satisfactory results when normalized or air quenched and drawn and with the analysis given below:

C.	Mn.	S.	P.	Cr.	Ni.
.45-.55	.50-.60	.04-.05	.05 Max.	.75-1.00	3.00-3.25

Boiler heads made of these alloys when annealed give properties that will correspond to rigid specifications. (Table 2 and Fig. 7.) The properties shown indicate that very high pressures can be used without chance of failure. The possible shock resisting properties after slow annealing are very interesting.

The ability to weld these materials adds to their value in many places. Alloy steel materials can be used in welding, followed by annealing operation for refining and removing the strains.

Table 1

Data for Curve of Fig. 6.

Chemical analysis: C—.55 per cent; Mn—.56 per cent; Cr—.95 per cent; S—.051 per cent; P—.028 per cent.

All bars quenched in boiling water at 1550 degrees Fahr.

Bar No.	Yield Point, Lbs. Per Sq. Inch.	Ultimate Strength, Lbs. Per Sq. Inch.	Elongation, Per Cent.	Reduction of Area, Per Cent.	Sclero-scope Hardness.	Heat Treatment, Degrees Fahr.
1	.....	83,350	....	....	70	As quenched
2	213,800	218,150	3.90	5.72	48	Drawn at 700
3	182,850	186,200	3.90	5.42	45	Drawn at 800
4	160,000	170,100	9.37	13.00	43	Drawn at 900
5	147,150	153,200	7.31	18.14	42	Drawn at 1000
6	124,100	137,050	14.06	30.90	37	Drawn at 1100
7	105,750	122,500	17.19	38.60	35	Drawn at 1200
8	89,350	107,300	21.87	43.75	35	Drawn at 1300
10	70,500	107,200	24.21	36.22	32	Drawn at 1400
11	68,000	110,800	16.40	18.00	28	Air cooled from 1550

Table 2

Data for Curves of Fig. 7.

Chemical analysis: C—0.31; Mn—0.55; Ni—0.56; Cr.—0.25; S—0.04; P—0.035.

Bar No.	Yield Point, Lbs. Per Sq. In.	Ultimate Strength, Lbs. Per Sq. In.	Elongation, Per Cent.	Reduction of Area, Per Cent.	Sclero-scope Hardness.	Heat Treatment.
C 1	69,750	101,600	14.06	16.23	31	Double anneal 1—1600 2—1500
C 2	80,050	94,500	17.96	42.75	32	Q.* Draw 1300° F. 1 hr.
C 3	196,900	197,950	.78	.77	58	Q.
C 4	189,300	195,000	2.34	4.25	49	Q. Draw 700° F. 30 min.
C 5	123,000	134,200	....	13.23	45	Q. Draw 800° F. 30 min.
C 6	134,000	146,850	9.37	23.70	41	Q. Draw 900° F. 30 min.
C 7	121,800	134,000	9.37	23.60	38	Q. Draw 1000° F. 30 min.
C 8	106,150	121,650	12.50	29.50	35	Q. Draw 1100° F. 30 min.
C10	87,600	102,250	20.31	42.70	30	Q. Draw 1200° F. 30 min.
C11	73,750	111,850	20.31	28.50	35	Q. Draw 1300° F. 30 min.
C12	65,600	85,800	11.71	10.16	28	Q. Draw 1400° F. 30 min.
C13	71,550	95,200	23.44	25.10	27	Slow cool from 1550° F.

*Q.—Quench for all bars in boiling water from 1550 degrees Fahr.

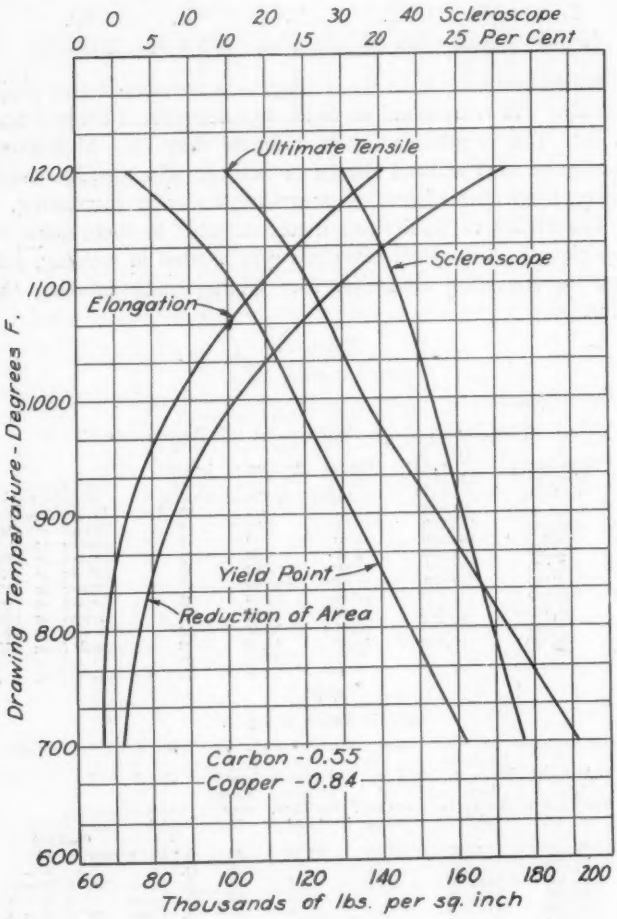
0 10 20 30 40 Scleroscope
0 5 10 15 20 25 Per Cent
Ultimate Tensile
Scleroscope
Elongation
Yield Point
Reduction of Area
Carbon - 0.55
Copper - 0.84
Drawing Temperature - Degrees F.
1200
1100
1000
900
800
700
600
60 80 100 120 140 160 180 200
Thousands of lbs. per sq. inch

FIG. 8

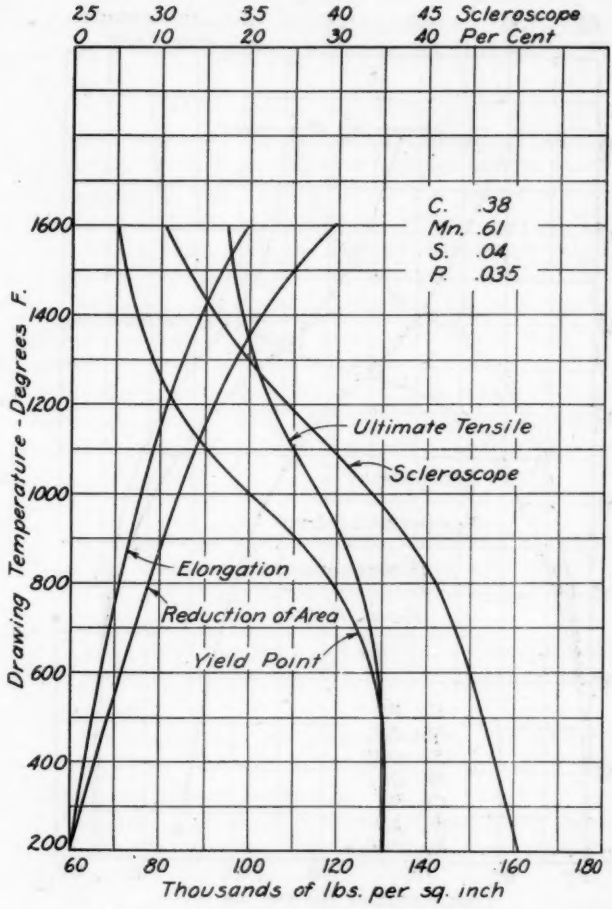
25 30 35 40 45 Scleroscope
0 10 20 30 40 Per Cent
C. .38
Mn. .61
S. .04
P. .035
Ultimate Tensile
Scleroscope
Elongation
Reduction of Area
Yield Point
Drawing Temperature - Degrees F.
1600
1400
1200
1000
800
600
400
200
60 80 100 120 140 160 180
Thousands of lbs. per sq. inch

FIG. 9

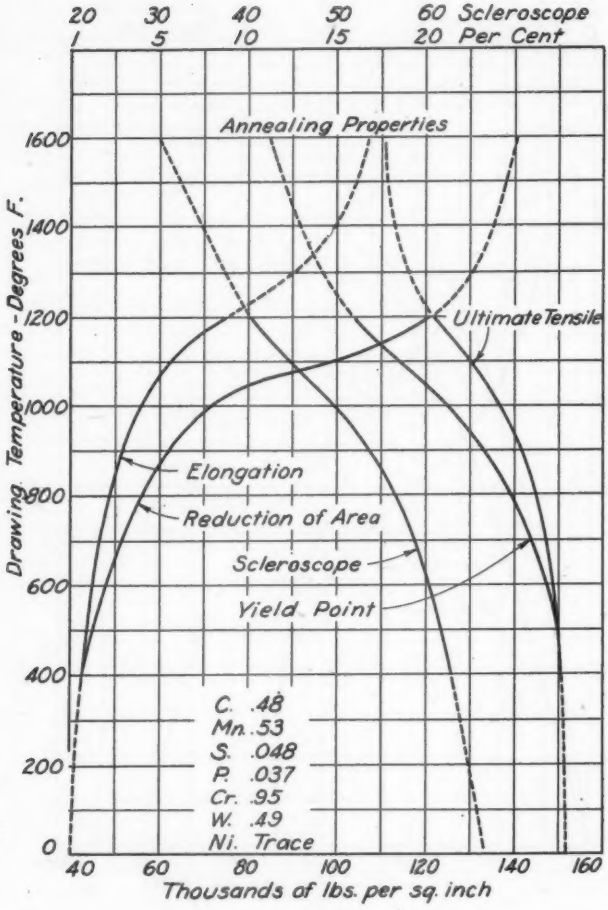
20 30 40 50 60 Scleroscope
1 5 10 15 20 Per Cent
Annealing Properties
Ultimate Tensile
Elongation
Reduction of Area
Scleroscope
Yield Point
Drawing Temperature - Degrees F.
1600
1400
1200
1000
800
600
400
200
0
C. .48
Mn. .53
S. .048
P. .037
Cr. .95
W. .49
Ni. Trace
40 60 80 100 120 140 160
Thousands of lbs. per sq. inch

FIG. 10

Miscellaneous

Under this heading can be mentioned chrome, vanadium, molybdenum and medium high manganese. Any of these alloys or mixtures in castings produce results that find numerous applications.

Molybdenum castings are being used for hydro-electric work, turbines, etc.; also many other castings where high tensile properties are desired. Medium high manganese (1.50 to 1.75) in connection with .30 to .40 carbon makes a casting very similar to one of the same carbon with high nickel. The elongation and tensile strength compare favorably with nickel or chrome nickel castings.

Bumpers and couplings could be made from this high manganese material, as could many other parts used in railroad work.

Varying amounts of copper can be added with an idea of imparting non-corrosive properties. The results of adding .84 per cent copper to a .35 carbon steel can be noted in Fig. 8.

Summary

1. Heat treating and addition of alloys give properties that recommend greatly increased application of castings.
2. It is practical to quench and draw high carbon and alloy steel castings.
3. Castings should be annealed before being treated.
4. Practically any analysis can be controlled within specification limits.
5. Carbon steels are used for gears, sprockets, trunnions, frames, axles, supports, farm machinery, tractors, bridge work, and general railroad work.
6. Alloy steels are used for chains, boiler heads, frogs, switches, dredging machinery, ordnance work, hydroelectric, tractor shoes, etc.
7. More information should be available in standard handbooks on properties and application of steel castings.

Discussion—Broadening the Field for Steel Castings

S. R. ROBINSON: I would like to ask Mr. Frey if the composition given just above Table 1 wouldn't be likely to be rather hard. The high carbon, medium high, and high nickel, and one per cent chrome I should imagine would be likely to be brittle.

H. J. FREY: We have not found steels of that analysis unusually brittle. It all depends upon the treatment that has been given them whether they are so or not. For a steel of that composition I would say it would be dangerous to quench in cold water. In that case you would get brittle steel. But you can vary your quenching operation with hot water, oil, or air; you can use high pressure air on it or merely lay it out in the ordinary atmosphere and let it cool, and in that way you get the benefit of the alloys without getting the brittleness.

S. R. ROBINSON: The paper, to my mind, is intensely interesting, and I think we all realize that there is a great field for not only soft castings to be annealed, but, of course, the hardened ones; that is, the heat treated ones. In our practice at the Bay City Industrial Works we make an alloy steel of carbon, vanadium and high manganese, about .35 carbon, 1.00 to 1.10 manganese and about 18 vanadium. We regularly meet 60,000 yield point, with 18 per cent elongation and 30 per cent reduction. When they require higher yield points on that steel, we give it an oil quench from 1,650 degrees Fahr. and a draw at 950 Fahr., and we get 90,000 elastic limit, with 18 per cent elongation. The regular treatment for the first steel is an air quench from 1,650 degrees Fahr. and a draw at 1,200 degrees Fahr. On the soft steel like that spoken of in this paper, we heat treat. We run a carbon about .18, with a manganese of around 1.00 per cent. We have run .80 and .90 to 1.00 per cent. We give that a water quench from 1,600 degrees Fahr. and a draw at about 1,000 degrees Fahr, 950, in fact, and get around 80,000 tensile strength. That responds very well to the water quench in cold water. We have found, though, in big open hearth castings outside, where the manganese runs down around .50 to .55, and the carbon around .25 to .28, there is a tendency to have water cracks. We don't know for sure whether it is due to the lower manganese or the higher carbon or just what. With our low carbon and the high manganese in the soft steel we have very little trouble with the water cracks.

MEMBER: I would like to ask Mr. Robinson what scleroscope hardness he gets with this low carbon, high manganese steel he spoke of last, the .18 carbon and about 1.00 per cent manganese.

S. R. ROBINSON: You mean after water quench?

MEMBER: After quenching and drawing, yes.

S. R. ROBINSON: On the casting we will get 30 scleroscope, 30 to 32. Of course, on a test bar you will get a lower scleroscope reading, due to the small mass.

S. L. HOYT: My eye caught this last statement in the summary, which is to the effect that "More information should be available in standard handbooks on properties and application of steel castings." I think if there were more papers of this type published, that it would be possible to put in more detailed information in the compilation. But, for one reason or another, it is very difficult to accumulate data on steel castings, the same as you can on steel in the rolled and forged shapes. The reasons are probably well known to everybody here, but just by way of explaining possibly why more information is not available, I simply wanted to call attention to the fact that there isn't very much information published, and the foundrymen—this has been true, at least, so far as my limited experience goes—do not seem to have the information available for people who are seeking it. So that if more work of this kind were published undoubtedly we will have much better information on steel castings, and possibly information which would be as good as that which is now available on rolled and forged material.

Organization and Practice in a Steel Foundry Finishing Department

By Charles W. Heywood, Chicago

Of the three main departments of a steel foundry, namely, molding, melting, and finishing, the latter is the only one whose working force is composed almost entirely of common or semi-skilled labor. Finishing department efficiency, therefore, depends to a large degree on skillful direction and management.

Organization

The Gang System

It is possible that in the very small foundry, one man may be able to supervise directly all the details of his department, but for the average foundry it is necessary that the foreman delegate some of his functions to well-trained subordinates. In the writer's experience it has been found that the gang system produces the most satisfactory results from the standpoint of both output and costs.

Under such a system each gang works under a leader who is directly responsible to the department foreman. These leaders should be experts in the particular operations of which they are in charge. Their duties, besides ordinary supervision, may consist of instructing new operators, inspecting material for both defects and workmanship, and checking the output of the different operators, if working on a piece-work basis.

The routing of work under the gang plan is quite simple. If special instructions are necessary in the case of rush orders or material requiring special attention, the foreman issues his instructions to the leader of the first gang. As the work proceeds, each gang leader in turn transmits these instructions to the leader of the next succeeding gang. In the case of special castings it may be necessary for the foreman to instruct each leader in the method of handling same.

Gang leaders should, in their own gang, hold the full prestige of the foreman. That is, the foreman should not interfere with the men in the different gangs except on the appeal of the workmen. He should give all his orders to the gang leader, thereby indicating to the men that their leader is acting with the foreman's authority, and is responsible for producing the work.

It is impossible for any foreman to give personal attention to every man in his department. With the gang system, however, the foreman need deal directly with only the five or six leaders who supervise the various gangs. This allows the foreman more time to devote to details such as the proper routing of work, experimenting, checking castings from new patterns as they come from the foundry; and a general inspection daily of castings from the foundry, so that irregularities may be reported to the foundry foreman.

The Pace Maker

Where the gang system is not feasible, another successful plan is to employ a pace maker. It is his duty to develop a best method of handling each new run of castings as it enters the shop, and by personal demonstration to instruct the men in carrying out the determined practice. Also, by actual performance, he establishes a definite time in which the various operations may be performed. From this trial, the foreman, after considering the pace maker's ability with the average ability of the gang, may establish a suitable piece-work rate.

It is necessary, of course, that the pace maker be thoroughly experienced in all the finishing operations. He should be interested and willing, and should work to full co-operation with the foreman.

For setting piece-work rates or daily output, either of the above methods, in the writer's opinion, is superior to the time-study system, since all determinations are standardized by an experienced operator. It is not possible to stand over a man with a stop watch and tell whether he is doing a fair amount of work or stalling, nor is it possible to determine a fair piece rate from such a test unless the performer's ability is accurately known.

Layout of Equipment

While layout will depend largely on local conditions, the following scheme will be found very satisfactory for economical production. The flogging floor should be of sufficient size to hold a day's run of the foundry. The annealing furnaces should be arranged at right angles to the flogging floor near one end; the sand blast at right angles near the opposite end, followed in order by the acetylene torches and welding equipment, grinding machines, chipping benches, tumbling barrels and lastly the benches for final inspection. In locating these different units, care should be taken to place them in such a manner as to avoid all unnecessary carrying, laying down, and picking up. Care must also be taken not to place them so close as to cause crowding. Some shops arrange benches along the route of small material in order to avoid picking up, and it is a very good system.

Lift trucks are very convenient and economical for moving castings, although of course the overhead crane is usually to be preferred. In laying out a finishing department, the most important consideration is to keep the material moving forward all the time; it should never move backward.

If the finishing department is laid at right angles to the foundry, there can be no disputes over crane preference, which otherwise are usually decided in favor of the foundry at the expense of chipping room efficiency.

Routing

Routing work through the finishing department is one of the foreman's most difficult problems. The size and shape of castings, and the condition in which they come from the foundry are all factors which affect the routing. At the same time the foreman must keep the different pattern numbers separate as much as possible, especially if he is behind the foundry output.

The following outline has been successfully carried out at the different plants with which the writer is connected:

1. Flogging, sprue cutting, and rough inspection.
2. Annealing.
3. Sandblasting.
4. Flame cutting of large heads and gates, followed by

further inspection. At this point, such castings as require welding are sent to the welders, while castings which pass inspection go to the grinders. Small castings go to one battery of grinders, large ones to another. Castings of intricate design with deep curves and angles go to the emery wheels of large diameter, and castings of plain design, with straight surfaces, go to the smaller diameter wheels.

5. Chipping.

6. Final finish. At this point, in shops equipped with both tumbling barrels and sand blast, small castings are sent to the former, and large castings and gears to the latter.

7. Final inspection.

8. Shipping floor.

Material, except in most urgent cases, should never pass by an operation until finished. For instance, if for some reason the grinders are delayed while the chipping keeps to schedule, the writer believes it would be preferable to send the chippers home rather than to chip the castings before grinding and then be obliged to send them back for grinding. Any procedure which upsets the routing will cause confusion and delay, and thereby increase the costs.

Operations

Flogging.—The first consideration is the floor. A good floor can be made by laying, on a level sand foundation, steel plates 1½ inches thick, 2 feet wide, and 3 feet long. These plates may be cast in open mold, from off-grade heats.

In breaking off heads and gates they should be nicked, especially at the corners. While this can be done with sledge and cold set, an air-hammer is to be preferred. Heads and gates should be broken away from, and not toward, the edge of the casting. When heads and gates are of the same size or larger than the section to which they are attached, it is safer to use the acetylene torch. Boxes may be provided, convenient to the floggers, into which the broken heads and gates can be thrown as soon as they are broken off.

Refuse sand should be cleaned off the floor daily.

Annealing.—Many plants consider it advisable to anneal

after sandblasting, while some sandblast both before and after the anneal. We prefer to anneal before the blasting operation, as the scale formed during the anneal loosens considerable sand, and the scale itself is easily removed in blasting. The proper procedure will no doubt depend on the nature of the castings and the peeling qualities of the facing sand.

When a car-bottom furnace is used, two sets of false bottoms may be provided. While one set is in the furnace, the other can be loaded for the next charge. If the furnace is not of the car-bottom type, it is very convenient to use a charging car similar to those used in rolling mills or on open hearth furnaces.

Sand Blasting.—The size of the castings will determine the type of sand-blast equipment. For medium and large size castings, the table room type is well adapted. Extra large castings will demand a room with car, while small castings, weighing 20 pounds and under, can be handled very well in a sand-blast barrel.

In our experience the fastest and most economical abrasives are those that come in the natural state.

Two men, namely a blower and a helper, are needed in each room. The helper watches the sand separator, elevator, etc., to prevent blockades; he also loads and unloads the castings.

In blowing, the best results are obtained by holding the nozzle about 6 inches from the work, and at an angle of 45 degrees. The mixture of sand and air is important; when correctly adjusted, there is a light blue streak at the nozzle. The air pressure should not be less than 85 pounds. It is a waste of time and material to attempt the blowing of steel castings with 75 pounds or less.

A nozzle made of mild steel gives very good results and can be made in the plant. The best nozzle is two or three inches long, with 5/16 inch hole. If using a very fine abrasive, a smaller hole is necessary.

The hose is an expensive part of the equipment, and wears out very rapidly near the tank end. By loosening the connection and giving the hose a quarter turn every second day, the life of the hose will be more than doubled.

Grinding.—In grinding an important point is to run the wheels at a definite peripheral speed, rather than at a uniform R. P. M. With the type of wheel employed by the writer, best results are obtained with a peripheral speed of 6500 feet per minute. To maintain the correct peripheral speed, arrange different R. P. M. on the various machines and start the maximum diameter stone on the lowest R. P. M. machine. After wearing off about four inches, transfer the stone to the next higher R. P. M. machine, and so on until it is worn down to about eight or ten inches diameter. By this method maximum service is obtained, with very little discard. Of course, the ideal installation would have direct driven machines with variable speed motors.

All grinding stands should be of heavy design and placed on a good concrete foundation.

To increase the operator's output, arrange some device which will give him a greater leverage. A simple arrangement is made by the use of a lever made of hard wood, about 2 inches square by 24 inches long. To this lever, at one end, is attached a short piece of chain by means of a ½ by 3 inch eyebolt. The chain in turn is secured to the grinding stand by a small hook, in such a way that the length of the chain may be adjusted at will, to suit castings of different size.

Chipping.—A bench 26 inches high, with blocks of wood nailed on in the form of jigs to hold the work, is very satisfactory for chipping small castings. Where there are long runs of the same castings, it is better to use a permanent jig of iron or steel. A very good arrangement for castings running from 50 up to 1500 pounds, is an empty oil barrel sawed off to about 24 inches. Fasten this to the floor, bottom side down, with angle irons. Bolt a ½ inch by 2 inch ring around the top and fill with sand. This allows the chipper to get all around the work.

A good tool for cleaning out long holes and smoothing off rough spots in grooves or corners, is a round tool with a flat end. For cleaning out burrs and slight fins in holes through thin sections, a tool with a slow taper is very useful.

Many chippers damage their air hammers by not holding them firmly to the work. Using an air hammer in this way will

very often break the handle where it is screwed to the barrel.

Tumbling.—Various sized barrels should be used to secure the best results. The following practice produces a very good finish:

Fill the barrel about one-third with jacks, pack the castings in tight, and throw in a discarded emery stub broken into pieces about the size of the fist with a little more than one-half pint of fuel oil. Tumble for three hours.

Care of Machinery and Tools

To avoid delays and loss of tools, every finishing department should have a tool room in charge of a good man. It is not necessary to have a first class mechanic; a good handyman will do if he is conscientious and interested in the work. While he should have the ability to make repairs, his main duty is to prevent them. He may be under the supervision of the mechanical department, but subject to the orders of the finishing department.

The tool room may be about 8 by 12 feet, and in it are all spare parts for the machinery, and tools can be kept in order. A place may be arranged where the men can store their tools at the end of the day. If such provision is not made, a man who takes pride in his tools will invariably hide them, and in such a case, if he quits overnight, the possibility is that the tools are lost.

We do not find it good policy to have a man grind tools for the chippers, because chippers invariably think no one can grind a tool as they can, and will regrind it anyway.

Inspection

The best inspection is secured when every operator is trained to inspect his own work. This is accomplished by refusing to pay for work done on scrap castings. When an operator believes a casting to be defective, he sets it aside until the foreman or a regular inspector comes around to pass on same. This slight delay is more than covered by the saving in labor to the operator and the company.

In some plants the inspection does not start until the cast-

ings are finished, whereas it should start on the flogging floor, or even in the foundry itself. A very good practice is to provide one or more places where scrap may be accumulated until it can be checked off and inspected by the shop foreman. Once this is done, the scrap should be loaded immediately and sent to the yard. While the finishing department foreman cannot look at every casting that passes through his department, he can and should inspect all scrap castings before they are sent to the yard. If he does this, he is in a position to safely instruct all his men in the scrapping of doubtful castings.

In regard to castings being scrapped, it is not good policy for the foundry foreman to have any authority in this question, because naturally he will be inclined to pass questionable material in order to hold his scrap down. This authority should be with the finishing department foreman, as he must take the blame for castings rejected by the customer. If the foundry foreman questions his decision, the case should be passed to the management for decision. This does not apply, of course, where an independent inspection bureau is maintained.

Cost

One of the best methods for reducing costs is to furnish the finishing department foreman with an itemized cost of production semi-monthly. By this means he can watch the different items, such as labor, power and material, and thereby be able to develop means for reducing same. Without furnishing him this information, the management can hardly hold him responsible for his costs, nor does it do any good to furnish such information one or two months later, for by that time the foreman will have forgotten the conditions prevailing at the time and will no longer be interested.

The gang system is a big aid in reducing costs if the foreman will carry it through in the proper manner. By keeping the gang leaders advised whether their costs are up or down, he gains their interest, and with a little diplomacy can create a friendly rivalry between the various gangs. This can be done without letting them know the actual cost per ton.

The cost of welding is a large item in every plant, and is

always charged to the finishing department. This is really a mistake. The finishing department has absolutely no control over the amount of welding to be done, this being entirely up to the foundry. If this cost was placed on the foundry, the foundry foremen would have the same incentive to reduce welding costs as they have to reduce scrap.

Wages

The matter of wages is always a delicate question. Some shops have been very successful in reducing costs by paying a higher rate of wages, thereby securing better workmen and having them satisfied. By so doing, fewer men are required to get out a specified tonnage, and labor turnover is reduced. It is really cheaper to pay one first-class man six dollars a day than to pay two poor men three dollars each. The first-class man will produce the same amount as the two second-class operators, while at the same time only one set of tools need be maintained instead of two. Actually, the saving in tools is more than this, since a good man takes better care of his tools and the cost of maintenance is thereby lowered. Also, the first-class operator will save more than fifty per cent on other items, such as air, power, abrasives, welding rod, etc.

There seems to be a modern tendency to set an arbitrary hourly rate. This to us seems wrong, because all men are not alike; although an arbitrary rate tends to make them so, but in the wrong direction. The only incentive for the good man is to come down to the production level of a poor operator, which ninety per cent of them do. The best practice is to establish a basic rate for starting, and later rate a man according to his ability.

It is poor policy to cut piece-work rates simply on the plea of excessive earnings. This kills the object of piece-work. If the rate is too high, it is up to the foreman to devise some change in the operation that will give him reason for changing the rate. The real object of piece-work is to arouse the dormant ability of the operator. On an hourly rate, the average man works automatically, while on piece-work he not only increases his physical effort, but his mental effort as well. He

will change his tools, or his rigging, develop a systematic movement, and by other means increase his output. He is therefore entitled to whatever earnings he can make. Cut the rate and you will kill this spirit.

Foreman

Most managements have long since ceased to give the finishing department a minor rating. Its influence on costs is well known, and the selection of a foreman demands careful consideration.

A finishing department foreman must have the full confidence of the management, and receive authority equal to the responsibility placed upon him. Practically, he should be able to do personally all the operations in his department, in order that he may capably judge the output of his men and establish piece-work rates.

The foreman of a finishing department stands in a very difficult position, in that he must take castings from the foundry in whatever condition they are produced and make of them a product acceptable to the customer. If obliged to call the foundryman's attention to a poor lot of castings, the only satisfaction he usually gets is to be told how it happened; and likely the next lot will be worse. At the same time, he can offer no excuse to the customer. It is quite possible that a little extra welding, grinding, or chipping, may make a casting with surface defects look very creditable, and it is part of the foreman's duty to decide just how far to go in such cases, without detriment to the buyer's interest. On the other hand, the foundry may produce very good castings which, if not properly finished, make a poor impression on the customer. It is obvious, therefore, that a finishing department foreman must be honest to the highest degree, and conscientious in his work.

Conclusion

In presenting the above ideas, it is realized that some modifications may be necessary in order to adapt them to local conditions. Every foundry confronts its own peculiar problems; nevertheless, it is hoped that the suggestions herein may prove of general interest.

Discussion—Organization and Practice in a Steel Foundry Finishing Department

By J. D. Towne, Dayton, Ohio

It is surprising to find at this late date any manufacturing executive who will still maintain the correct method of determining a proper "daily output" is through the "Gang System," or by use of a "Pace Maker," rather than by time studies! Mr. Heywood does not explain how the "piecework rates or daily output" are to be determined by the "Gang System," and it can only be assumed that the gang leader is intended to personally set the rate from his experience, and that this rate is made for the gang as a whole, the total amount of earnings being divided proportionately between the several members.

The weak points of this plan are obvious. I say, without fear of contradiction, that no foreman nor gang leader, nor anyone else, has, as yet, been found who can set equitable rates based on his own past experience, and this statement has repeatedly been proven a fact in plants using this method for setting rates—rates that are repeatedly cut as the workers' daily productions top the figures set by the foremen's successive guesses, until the workers realize the only way to protect themselves is to limit their output to a point close to what has been considered a good figure by the foremen.

And aside from the method of determining the proper daily output, the idea of setting a rate to cover a group of men, when it can be set for each individual separately, or for a smaller group, is bad practice, tending to limit production. No two men in a gang, department, or plant, are exactly equal in productive capability or ambition, and it is this fact that makes it desirable to set rates on individuals rather than on a gang as a unit. When several men work together, and split their earnings, each worker is naturally watching his fellows, fearing that they are not putting forth the same effort that he is, and as he

becomes convinced that this is a fact he slows down to meet what he considers the pace of the others in order that he may not be contributing to their pay beyond the point that they are contributing to his. Water always settles at the lowest level—and so it is with labor—it is easier to slip down than to climb up, and the gang's working level repeatedly drops to the plane of the poorer men. (Mr. Heywood is in sympathy with this thought as stated in his paper under the heading "Wages".) When a man works only for his own benefit and he realizes his earnings depend entirely upon his individual effort, it is natural that he will be more willing to put forth his maximum energy.

If Mr. Heywood meant in the gang system to have the men all working day work and have the gang leader responsible for their output, it would be even more hopeless to maintain maximum production. The advantages of any incentive wage system over straight day work have been discussed too frequently to call for any further discussion at this time; but it might be added that a series of actual performances in many large and small plants, covering various industries throughout this country, have demonstrated that the average day worker produces less than fifty per cent of a fair day's work.

The plan of using a pacemaker to determine the proper daily output for any given job, is but little better than the gang system. If we could be certain that our pacemaker would work on each and every job at a consistent gait, equal to the speed of a good worker, and at the same time allow for necessary fatigue, if we had a man who was capable of "developing a best method of handling each new run as it entered the shop," and if we had a man who "by personal demonstration" could "instruct the men in carrying out the determined practice," we would have an executive who would be entirely too valuable a man to be employed as a pacemaker, but I do not believe any pacemaker has ever measured up to this high standard set by Mr. Heywood.

Evidently, Mr. Heywood realizes the pacemaker is somewhat of an unknown quantity when he states "the foreman, after considering the pacemaker's ability with the average ability of the gang, may establish a suitable piecework rate." In other

words, the performance of the pacemaker assists the foreman in making his guess, and the accuracy of this guess depends entirely upon the reliability of the pacemaker.

No worker, no matter how experienced or capable, can work at the same speed and with the same interest day in and day out, especially when his jobs are constantly changing. This means, when the pacemaker works a job just to his liking on a day when everything is running along smoothly and he is feeling top notch, the rate determined will be set tight, and the other workers will probably have a hard time to steadily equal his record; while just the reverse will be true when conditions are not so ideal, and the pacemaker is working along with a headache or tired from loss of sleep the night before. As long as we deal with human nature we will find fluctuations in performances and consequently any rates set from such performances will fluctuate in the same degree.

But even a more serious objection to the pacemaker is the discord he always breeds in a shop. The pacemaker is the most unpopular man with the other workers and there is always a feeling that the management uses rates that even the pacemaker never has made and could not make if he tried, although this practice may not actually exist in all shops where a pacemaker is used. Lack of harmony in the shop is a serious condition and anything tending to destroy confidence in the management should be carefully avoided.

When endeavoring to determine the value of time studies in any shop, whether employing skilled, semi-skilled, or common labor, several points are absolutely necessary, but the principal requirement is to have a time study observer who knows his business thoroughly, has the proper personality, and fully understands the principal points of the class of work he is going to study. If such a man is making the time study he cannot only "stand over a man with a stop watch and tell whether he is doing a fair amount of work or stalling," but he can also "determine a fair gang rate from such a test without knowing the performer's ability."

In properly making a time study, instead of taking an over-all time from the beginning of the job until it is finished, the many

elements or sub-operations, that go to make up the complete job, are separately timed on possibly ten to twelve successive pieces; by analyzing these times and through careful comparison any stalling, or even lack of ability, is shown up so plainly that it cannot be missed, and it is a comparatively simple matter for the time study man to pick out the proper times for each element, and by adding them together determine accurately the minimum time in which the operation can be done. To this time should be added an allowance for fatigue and unavoidable delays that occur through the day. This allowance will vary with the class of work being done but will usually amount to about twenty per cent.

In considering the possibilities of modern methods of management, including time study, etc., in the foundry it would be well to recall a paper written by Frederic A. Parkhurst, M. E., and published by the American Foundrymen's Association in Volume XXIII of the transactions. Mr. Parkhurst says, "as a general proposition, the foundry offers neither more nor less in the way of difficulties to be overcome when installing scientific management than other lines of business . . . . On the other hand, the possibilities of the scientific methods are greater in the foundry than perhaps any other metal industry."

Frederick W. Taylor, past president of the American Society of Mechanical Engineers, in a paper read before that society said, "The writer has found, through an experience of twenty years, covering a large variety in manufacturers, as well as in the building trades, structural and engineering work, that it is not only practical but comparatively easy to obtain through a systematic and scientific time study, exact information as to how much of any given kind of work either a first-class or an average man can do in a day, and with this information as a foundation, he has over and over again seen the fact demonstrated that workmen of all classes are not only willing, but glad to give up all idea of soldiering, and devote all of their energies to turning out the maximum work possible, providing they are sure of a suitable permanent reward." In another paragraph Mr. Taylor continues, "with accurate time study as a basis, the 'quickest time' for each job is at all times in plain sight of both employers and workmen, and is reached with accuracy, precision and speed."

Mr. Taylor's words have been proven out time and time again in all sizes of plants, representing practically every industry, until today time study is recognized as a very essential arm of management, absolutely necessary in the life of any progressive manufacturing organization.

AUTHOR'S REPLY:

1st Paragraph: Mr. Towne is under a wrong impression about the "Gang system" being paid a gang rate. I do not believe in a gang rate to be divided among the men, but always set the price on the piece and a separate price for each operation. Mr. Towne is excuseable in making this mistake because in printing the paper, on page 3, 2nd sentence, 3rd paragraph reads "fair gang rate" instead of "fair price rate."

2nd Paragraph: I take exceptions to his statement "That no equitable rates can be set except by the time study system." In the writer's experience, under the gang leader system, rates have been set that reduced costs 30 per cent and remained in effect for years without change.

3rd Paragraph: I fully agree here with Mr. Towne as he makes the same statement, using arrangement of words, as I do under heading "Wages."

4th Paragraph: If Mr. Towne had read the paper carefully he would not assume that I advocate working all the men day work, for the paper very clearly shows the advantage of piece work. But under the gang leader system even the men on day work are kept far above 50 per cent efficient.

5th Paragraph: Here Mr. Towne assumes that the pace maker goes through his work or demonstrations without anybody being interested in what he is doing. At these times the foreman is very much on the job. The writer has developed several pace makers who measure up fairly well to Mr. Towne's specifications but being only semi-skilled mechanics, lack, due to education or natural ability, the valuable executive ability of which Mr. Towne speaks.

7th Paragraph: I will answer this by reminding Mr. Towne that the same conditions are true of the time study system, but

more so because he has the operator and time study man to contend with in regard to off color stomachs, headaches, lack of sleep, etc.

8th Paragraph: In the writer's experience, there has been more discord with the time study method than with the pace maker method for the reason that the pace maker is looked upon by the other men as one of their own. The time study man is considered on the other side of the fence, and looked on with suspicion. The writer never had an occasion where the men felt that rates other than those arrived at by the pace maker were being used. There have been times when certain operators have felt that the pace maker could not make a fair day's wage on the rate set. In a case of this kind there is only one thing to do, i. e., put the pace maker on the job and prove it.

9th Paragraph: When Mr. Towne gets a time study man such as he describes he will have his "valuable executive." There will be one requisite always missing "To set a fair rate without knowing the performer's ability." I wonder if Mr. Towne would set the output of an automatic machine without knowing the speed or horse power.

10th Paragraph The writer has had no experience with time study or other systems setting rates where machines are used, but thinks it would be possible to use the time study system to advantage there by reason of long runs and the small per cent of human element entering. I wonder how Mr. Towne would make, or if made, how he would use a time study when there are only a few castings made from a pattern. The writer has seen castings from 50 to 785 different patterns, ranging from 5 to 30 castings per pattern, go through the cleaning room complete in two days. In such cases the foreman alone, through his broader experience, can set piece work rates.

Report of Committee on Specifications for Steel Castings

To the Members of the American Foundrymen's Association:

During the past year there has been a good deal of discussion over the specifications for carbon steel castings and evidence of the growing tendency to remove from the general specifications such castings as are for very special purposes. This, perhaps, started a few years ago when castings for ship work were made the subject of special mention in the general specifications of the American Society for Testing Materials. Then, later, the carbon steel castings for railroads were by joint committee work made the subject of separate specifications and removed entirely from the general specifications of the A. S. T. M. In this connection we would call your attention to an error in the footnote of our report of last year as it was published in the Transactions of the Society, Volume XXXI. This footnote states that these tentative specifications, A87-22T, were adopted as standard. This is not so; they were adopted as tentative merely, and we can now report that at a meeting of the A. S. T. M. held in Atlantic City, June, 1924, they were voted to be continued as tentative for another year. This is rather important for note by anyone who is interested in railroad work. Our editors were under a misapprehension in stating in our report of last year that the specifications were adopted. They were simply adopted as tentative only, and were so continued this year. So there are yet no standard specifications for railroad work.

The A. S. T. M. during the year appointed a Sub-committee XXII of the Committee A-1 to frame specifications covering steel fittings for high pressure steam installations. This committee has been organized and has made a good start during the year. Messrs. Bull and Jameson were appointed on this committee as representing Sub-committee VIII of Committee A-1. This gives the American Foundrymen's Association good representation in the making up of these very important specifica-

tions and we shall welcome any suggestions which our members may make. The function of the committee is to deal with steel fittings for use up to 750 pounds pressure. Higher pressures may be considered later and all of the materials which enter into the construction of these valves, whether castings or not, will be considered.

The committee does not want it understood from this that only members of the American Foundrymen's Association, who are interested in this committee, are the two just mentioned now. These two are the official A. F. A. representatives. The chairman of the A. S. T. M. committee is V. T. Malcolm, whom you all know and who is a very much interested and a very active member of the A. F. A. but who has not yet had official appointment to this A. S. T. M committee as a representative of the A. F. A.

After considerable deliberation the A. S. T. M. Sub-committee on Steel Castings recommended that the Tentative Standards be adopted as standard with a few minor changes. The annual meeting of the A. S. T. M. at Atlantic City in June approved of these changes and they were, according to recommendations of the Society, sent out for letter ballot. The ballot has just been cast and the result shows that the recommendation is approved so that the tentative specifications with these slight modifications will now become standard. The full copy with changes follows this report as appendix A.

The above paragraph means that the tentative specifications for general steel castings have now been made the standard of the American Society for Testing Materials and that the labors of the sub-committee are, to a large extent, ended.

This report is presented to you simply as a report of progress. It is a report of what has been done, but any suggestions or corrections or additions would be gladly considered by the committee.

A. H. JAMESON, *Chairman.*

Appendix A—Report of Committee on Specifications for Steel Castings

Standard Specifications for Steel Castings

A. S. T. M. Serial Designation: A 27-24

Material Covered.

1. These specifications cover steel castings for general service and for ships. Two classes of castings are covered: namely,

Class A, castings for which no physical requirements are specified.

Class B, castings for which physical requirements are specified. These are of three grades: hard, medium, and soft.

I. MANUFACTURE

Process.

2. The steel shall be made by one or more of the following processes: open-hearth, electric furnace, converter, or crucible.

Heat Treatment.

3. (*a*) Class A castings need not receive any heat treatment unless so specified, or unless the carbon content exceeds 0.30 per cent.

(*b*) Class B castings and Class A castings in which the carbon content is over 0.30 per cent, shall receive a heat treatment proper to the design and chemical composition of the castings.

(*c*) Heat treatment, unless otherwise specified by the purchaser, may consist of annealing, or of normalizing, or of normalizing followed by annealing, or of normalizing followed by a draw-back to a temperature below the critical range. No castings which have been quenched in any liquid medium shall be offered under these specifications.

(*d*) *Annealing.*—The procedure for annealing shall consist in allowing the castings to cool after pouring, to a temperature below the critical range. They shall then be uniformly

reheated to the proper temperature to refine the grain, and allowed to cool uniformly in the furnace.

(*e*) *Normalizing.*—The procedure for normalizing shall consist in allowing the castings to cool after pouring to a temperature below the critical range. They shall then be reheated to the proper temperature to refine the grain and allowed to cool in still air.

II. CHEMICAL PROPERTIES AND TESTS

Chemical Composition.

4. The castings shall conform to the following requirements as to chemical composition:

	Class A	Class B
Carbon	not over 0.45 per cent	....
Phosphorus, Acid	not over 0.07 per cent	not over 0.06 per cent
Phosphorus, Basic	not over 0.06 per cent	not over 0.05 per cent
Sulfur	....	not over 0.06 per cent

Ladle Analyses.

5. An analysis of each melt of steel shall be made by the manufacturer to determine the percentages of the elements specified in Section 4. This analysis shall be made from drillings taken at least ¼ in. beneath the surface of a test ingot obtained during the pouring of the melt. The chemical composition thus determined shall be reported to the purchaser or his representative, and shall conform to the requirements specified in Section 4.

Check Analyses.

6. (*a*) Analyses of Class A castings may be made by the purchaser. The phosphorus content thus determined shall not exceed that specified in Section 4 by more than 20 per cent. Samples for analysis shall be taken not less than ¼ in. beneath the surface, and in such a way as not to destroy the castings.

(*b*) Analyses of Class B castings may be made by the purchaser from a broken tension test specimen. The phosphorus and sulfur content thus determined shall not exceed that specified in Section 4 by more than 20 per cent.

III. PHYSICAL PROPERTIES AND TESTS

(For Class B Castings Only)

Tension Tests.

7. (*a*) The castings shall conform to the following minimum requirements as to tensile properties:[1]

	Hard.	Medium.	Soft.
Tensile strength, lb. per sq. in.	80,000	70,000	60,000
Yield point, lb. per sq. in.....	0.45 tens. str.	0.45 tens. str.	0.45 tens. str.
Elongation in 2 in., per cent..	17	20	24
Reduction of area " ..	25	30	35

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

Bend Tests.

8. (*a*) Bend tests shall not be required for castings of the hard grade, and shall be required for castings of the medium and soft grades only when so specified in the order.

(*b*) When a bend test is specified, the test specimen shall withstand being bent cold without cracking on the outside of the bent portion, around a pin 1 in. in diameter to the following angles:

	Hard.	Medium.	Soft.
Angle of bend.....	No Bend Test	90 deg.	120 deg.

Alternative Tests to Destruction.

9. The tensile properties of the castings shall be determined from test bars unless in the case of castings weighing not over 150 lb. the manufacturer desires to offer, as an alternative, tests to destruction. Upon agreement with the inspector, the castings shall be grouped in lots, each lot containing castings from the same melt and from the same heat-treatment charge, and the inspector shall select from each lot one casting to represent the lot. The representative casting shall be tested to destruction as a substitute for the tension test. This test shall show the material to be ductile and free from injurious defects.

[1]Because it has come to the attention of Committee A-1 on Steel that the intent of the requirement of Section 7 (*a*) has at times been misinterpreted, the committee wishes to make it clear that it is not intended that maximum limits shall be placed on the tensile strength in any of the grades specified.

Test Specimens.

10. (*a*) Tension and bend test specimens shall be taken from test bars cast attached to the castings where practicable. If the design of the castings is such that test bars should not be attached to the castings, the test bars shall be cast attached to special blocks, of which a sufficient number shall be provided for each lot of castings. Test bars from which tension and bend test specimens are to be taken shall remain attached to the castings or blocks they represent through heat treatment and until presented for inspection. Test bars shall be provided in sufficient numbers to furnish the tests required in Section 11.

(*b*) If satisfactory to the manufacturer and inspector, tension test specimens may be cut from heat-treated castings instead of from test bars.

Tension Specimens.

(*c*) Tension test specimens shall conform to the dimensions shown in Fig. 1. The ends shall be of a form to fit the holders of the testing machine in such a way that the load shall be axial.

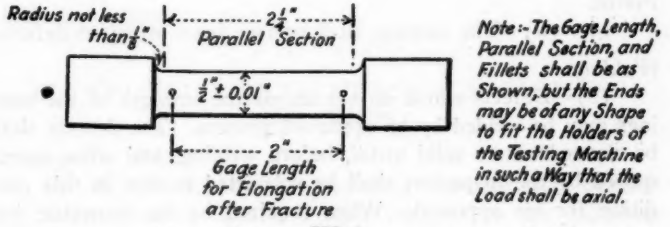
Radius not less than 1/8"
2 1/4" Parallel Section
1/2" ± 0.01"
2" Gage Length for Elongation after Fracture
Note:-The Gage Length, Parallel Section, and Fillets shall be as Shown, but the Ends may be of any Shape to fit the Holders of the Testing Machine in such a Way that the Load shall be axial.

FIG. 1

Bend Specimens.

(*d*) Bend test specimens shall be machined to 1 by 1/2 in. in section with the corners rounded to a radius of not over 1/16 in.

Number of Tests.

11. (*a*) One tension test and, when specified, one bend test shall be made from each melt in each heat-treatment charge and, when specified, from each casting weighing 500 lb. or over.

(*b*) If any test specimen shows defective machining or develops flaws, it may be discarded; in which case another specimen from the same lot shall be substituted.

(*c*) If the percentage of elongation of any tension test specimen is less than that specified in Section 7 (*a*) and any part of the fracture is more than ¾ in. from the center of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

Retests.

12. If the results of the physical test for any lot do not conform to the requirements specified, such lot may be retreated, but not more than twice. Retests shall be made as specified in Sections 7 and 8.

IV. WORKMANSHIP AND FINISH

Workmanship.

13. The castings shall conform substantially to the shapes and sizes indicated by the patterns and drawings submitted by the purchaser.

Finish.

14. (*a*) The castings shall be free from injurious defects.

Welding.

(*b*) Defects which do not impair the strength of the castings may be welded by an approved process. The defects shall be cleaned out to solid metal, before welding, and when so required by the inspector, shall be submitted to him in this condition for his approval. When required by the inspector, important castings shall be heat-treated after welding.

V. INSPECTION AND REJECTION

Inspection.

15. (*a*) The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the castings ordered. The manufacturer shall afford the inspector, without charge, all reasonable facilities to satisfy him that the castings are being furnished in accordance with these specifications.

(*b*) If, in the case of important castings for special purposes, surface inspection in the green state is required, this shall be so specified in the order.

(*c*) All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejection.

16. (*a*) Unless otherwise specified, any rejection based on tests made in accordance with Section 6 shall be reported within five working days from the receipt of samples.

(*b*) Castings which show injurious defects subsequent to their acceptance at the manufacturer's works will be rejected and the manufacturer shall be notified.

Rehearing.

17. Samples tested in accordance with Section 6, which represent rejected castings, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

VI. SPECIAL REQUIREMENTS FOR CASTINGS FOR SHIPS

Castings for Ships.

18. In addition to the preceding requirements, castings for ships, when so specified, shall conform to the following requirements:

Heat Treatment.

19. All castings shall be of Class B, medium or soft grade, and shall receive a proper heat treatment.

Number of Tests.

20. (*a*) One tension and one bend test shall be made from each of the following castings: stern frames, stern posts, twin screw spectacle frames, propeller shaft brackets, rudders, steering quadrants, tillers, stems, anchors, and other castings when specified.

(*b*) When a casting is made from more than one melt, four tension and four bend tests shall be made from each casting.

Percussion Tests.

21. (*a*) A percussion test shall be made on each of the following castings: stern frames, stern posts, twin screw spectacle frames, propeller shaft brackets, rudders, steering quadrants, tillers, stems, anchors, and other castings when specified.

(*b*) For this test, the casting shall be suspended by chains and hammered all over with a hammer of a weight approved by the purchaser or his representative. If cracks, flaws, defects, or weakness appear after such test, the casting may be rejected.

Report of Representative on Joint Committee on Investigation of Phosphorus and Sulphur in Steel

To the members of The American Foundrymen's Association:

Your representative on the Joint Committee on the Investigation of the Effects of Phosphorus and Sulphur in Steel advises that the Joint Committee submitted at the Convention of the American Society for Testing Materials in June, 1924, its third preliminary report which dealt with tests on rivet steels. As in the case of former preliminary reports, the last one contained no recommendations or conclusions. These may be submitted when further progress in the investigation has been made.

It seems unnecessary to explain in any detail the nature of the third preliminary report which was given considerable publicity following its presentation.

Manufacture for the purpose of testing, and the various forms of tests have thus far been confined by the committee to the consideration of sulphur in steel made from ingots. It is impossible at this time to state when steel castings will be considered by the committee as a separate feature; or when the investigation will be undertaken into the effects of phosphorus in steel. Necessarily the joint research organized must proceed in a carefully systematic way that prevents hasty and possibly erroneous conclusions from being formed. It is believed that all co-operating bodies that are represented on this Joint Investigation will appreciate these facts and that engineers and metallurgists generally will realize that much time is required to do such work when it must be undertaken as a task to be performed without interfering with the regular activities of the investigators.

Suggestions from any member of the Association will at any time be gladly received by the Association's representative on the Joint Committee or by the Committee's secretary, Mr. C. L. Warwick, 1315 Spruce Street, Philadelphia, Pa.

Respectfully submitted,

R. A. BULL

A. F. A. Representative on Joint Committee on the Investigation of the Effects of Phosphorus and Sulphur in Steel

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Discussion—Report of A. F. A. Representative on Joint Committee on Investigation of Phosphorous and Sulphur in Steel

K. C. JOHNSON: I would like to ask what is the high point of sulphur that is found dangerous, and causes cracks in steel castings in his investigations up to date.

R. A. BULL: The subject of steel castings hasn't yet been reached in the investigation, and I think it is probable that that particular phase will not be touched, because it is the effects on the surface of the steel that are being investigated by the committee, not the handicap on the manufacturer. Of course, take in the matter of bolts, a great many people know that the high sulphur improves the machining qualities and therefore improves the opportunities of making threads. But it is not that sort of thing on which the committee is pursuing its investigation. They are trying to find out for the benefit of the purchaser, and consequently, the effect on commercial specifications, what the effect of phosphorous and sulphur in varying degrees are to the man who has to use the stuff after the parts go into service.

CHAIRMAN J. H. HALL: I expect, gentlemen, that we will all be much more gray headed when that committee gets around to steel castings than we are now. The amount of work that has been laid out is, as Major Bull has told you, really enormous, and steel castings won't be reached for several years.

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